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Research Paper
PNW-302

January 1983

Growth-Simulation Model for Lodgepole Pine in Central Oregon

Walter G. Dahms

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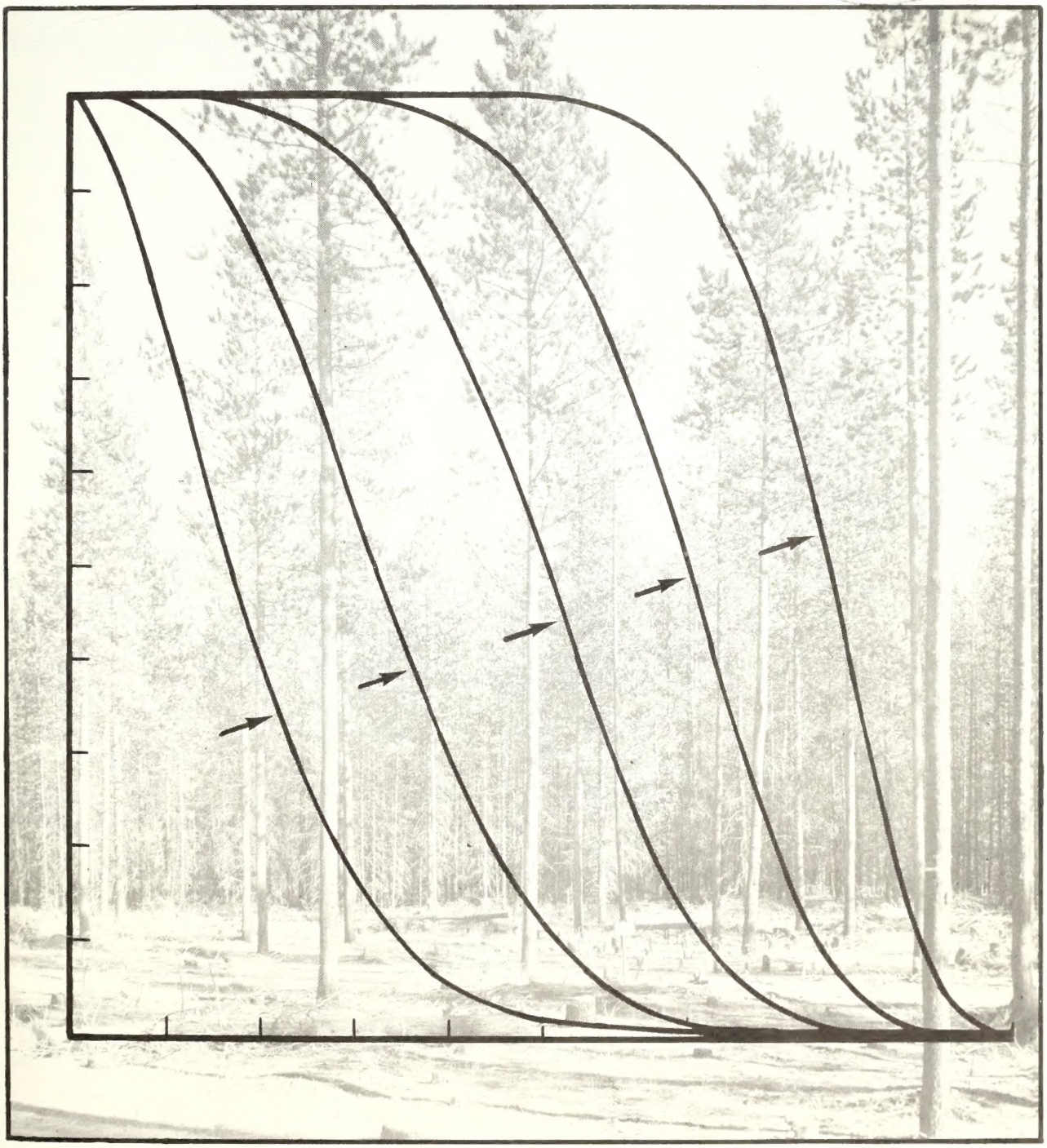

Author

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Abstract

Summary

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3. Simulated tree size was compared with actual tree-size distributions found on some temporary plots.

All of the comparisons indicated that simulations produced reasonable results. More comparisons over a longer period, like those in approach 1, would be desirable, but long-term records on permanent sample plots simply do not exist. The need for verification makes a strong case for continuing existing permanent sample plots.

The simulation model as presented is applicable to central Oregon lodgepole pine. The gross-volume-increment equation is based only on central Oregon data. The area of application could be broadened by gathering gross-volume-increment data from additional areas to determine if the existing equation fits, or to fit a new equation as the data might indicate.

Use of gross-cubic-volume increment as the main driving mechanism for the simulator with allocation of increment to individual trees, as has been done for lodgepole pine in this instance, would appear to have application for other species. This would seem to be especially true for a species such as ponderosa pine, where a considerable body of data from levels-of-growing-stock and spacing studies is available from a broad geographic area.

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Introduction

Direct comparison of timber-management alternatives, such as varying rotation lengths or stand-density regimes, requires such long periods of time that comparisons of this kind are not practical. Historically, yield tables have been used to make them. The computer-simulation model presented in this paper differs from conventional yield tables only in that it has greater flexibility in dealing with the stand-density variable and therefore is a more flexible and useful form of yield table.

New stands that are replacing the old growth now being harvested provide foresters with real opportunities to concentrate more of the wood produced by lodgepole pine forests on trees that will reach usable size and to minimize losses from mountain pine beetle (*Dendroctonus ponderosae* Hopkins). Simulation provides an opportunity to see how the many combinations of initial spacing and subsequent stand-density regimes affect tree size, total production, and rotation length, thus providing the forest manager and economist with a basis for choosing the most desirable alternative.

Multiple use of forest land, such as for production of both wood and wildlife, increases the options of the land manager and makes the job of selecting the best alternative more difficult. Simulation of forest growth makes results of a particular choice clearer and opens the possibility of estimating production of such wildlife needs as food and cover from the simulated estimates of forest stand density.

Volume estimates are in terms of total cubic, merchantable cubic, and board feet. Several options for the kind of merchantable cubic and board-foot volumes are provided. Merchantable cubic is all volume above stump to a 3.0-, 4.0-, or 5.0-inch top as specified by the user. Board-foot volumes may be either Scribner, or International ¼-inch-kerf. Merchantable tops of 5.0, 6.0, 7.0, or 8.0 inches may be specified for either log rule.

The paper is divided into three main sections:

1. Running the simulator, using a Hewlett-Packard 9845A desk-top computer;[1]
2. How the simulator works; and
3. An appendix providing details to judge underlying equations and assumptions.

[1]The mention of products and companies by name does not constitute endorsement by the USDA, nor does it imply approval of a product to the exclusion of others that may be suitable.

Running the Simulation Program

The simulation model consists of a package of programs for a Hewlett-Packard 9845A desk-top computer. The basic sets start where heights and diameters of all trees have been measured or where heights have all been estimated from curves of height over diameter.

The set designed to start from permanent sample plots with all tree heights and diameters measured is called "LPSIM" and "LPSIM1" (lodgepole pine simulation). This pair of programs is essentially one, but was broken into two parts connected with a "LINK" statement to save storage space on the computer.

The second set is designed to start from prism-point data where diameters of all trees and height of the tallest tree have been measured. Heights of trees where diameter only was measured are estimated from curves of height over diameter. This set of programs is called "LPPRI" (lodgepole pine prism) and "LPPRI1." They also are essentially one, but broken into two pieces connected with a "LINK" statement.

Differences between these two sets of programs arise because the height and diameter data are stored on tape differently.

Several support programs are also included in the simulation package:

1. "STORE" is used to enter diameter and height of each tree for storage on tape for entry into the "LPSIM" programs. To use this program, put the tape into the T15 slot and load "STORE." List the program to obtain further instructions.
2. "STORPR" is designed to convert diameters of trees and height of the tallest one at a prism point into height and diameter of each tree expanded to a 1/5-acre basis. Heights consist of regression-estimated heights plus or minus a random-error term. To use this program, load it into memory and list it for further instructions.
3. "SINDEX" is used to calculate a density-corrected site index from total height and breast-high age of a single tallest tree. Load this program into memory and list it to obtain instructions for using the program and measurements required.
4. "CCF" is designed to give a stand-density estimate in terms of crown competition factor (C.C.F.) from tree-diameter measurements at a prism point. To use the program, load it into computer memory and list it for instructions.
5. "INSTR" provides instructions for running the "LPSIM" programs. The instructions are obtained by loading "INSTR" into memory and listing it.
6. "INSTR1" provides instructions for running the "LPPRI" programs. To obtain the instructions, load "INSTR1" into computer memory and list it. Support programs appropriate for use with the "LPSIM" programs are stored on the tape with "LPSIM," and programs to be used with program "LPPRI" are stored with "LPPRI."

Summary tables give a great deal of information about the simulated stand (exhibit 1). Basal area, volume, number of trees, and average tree height by 2-inch diameter classes are given for the final year of the simulated stand. Other tables give live-stand values at 5-year intervals, trees that died by 5-year periods, trees cut in thinning, and increment and financial aspects of the stand at 5-year intervals. Site index, interest rate, time to which stumpage value is discounted, stumpage value, time of thinnings, and percent of stems to be cut are shown at the bottom of the summary tables.

Exhibit 2 shows tables produced if a complete printout is called for. These tables show basal area, volume, number of trees, and average height by 2-inch diameter classes. This information is needed to determine how many trees to cut and what volumes may be available by tree size for any possible thinning.

Grand summary tables, similar to those shown as exhibit 1, are also produced where more than one plot or more than one random start per plot is requested. These tables represent averages for a number of simulation runs.

The programs that make up the lodgepole pine growth-simulation model will run as written on the Hewlett-Packard 9845A desk-top computer. These programs can also be run on a Hewlett-Packard 9845B with only slight modification. Potential Forest Service users of these programs can obtain copies of these tapes from the Regional Office in Portland. Others can obtain copies from the Silviculture Laboratory in Bend.

Anyone wishing to adapt these programs for use on other computers may obtain a listing from the Silviculture Laboratory. The programs are written in BASIC, which is similar to FORTRAN.

EXHIBIT 1

JANUARY 8,1983
BEATTY CREEK SPACING STUDY,15X15 FEET,PLOT 9
SCRIBNER BD. FT. VOL. ALL TREES 7.6 INCHES D.B.H. & UP TO A 5 INCH TOP
MERCHANTABLE CUBIC VOL. ALL TREES 4.6 INCHES D.B.H. & UP TO A 3 INCH TOP
MANAGED STAND MORTALITY
ALL VALUES PER ACRE BASIS

PROJECTED BASAL AREA AND VOLUME BY TREE SIZES AGE 64

	BASAL AREA	VOLUME CUBIC TOTAL	VOLUME CUBIC MERCH.	VOLUME BD.FT.	NUMBER TREES	AVERAGE HEIGHT
TREES LESS THAN 4.6 INCHES	0.0	0			0	0
TREES 4.6 TO 6.5	0.0	0	0		0	0
TREES 6.6 TO 8.5	0.0	0	0	0	0	0
TREES 8.6 TO 10.5	0.0	0	0	0	0	0
TREES 10.6 TO 12.5	3.1	67	64	226	4	53
TREES 12.6 TO 14.5	16.2	363	350	1395	16	55
TREES 14.6 TO 16.5	33.3	786	766	3344	26	59
TREES LARGER THAN 16.5	43.5	1088	1069	5178	24	64
TOTALS OR AVERAGE	96.1	2303	2249	10143	69	60

SUMMARY TABLES

LIVE STAND STATISTICS

AGE	NO. TREES	BASAL AREA	CCF	AVG. DIA.	AVG. HT.	CUBIC VOLUME TOTAL	CUBIC VOLUME MERCH.	BD.FT. VOLUME
19	192	22.9	34	4.6	18.6	248	180	0
19	75	11.6	16	5.3	20.6	129	123	0
24	75	24.7	27	7.7	24.3	303	286	208
29	75	36.1	37	9.3	29.3	496	464	890
34	73	46.4	45	10.7	34.4	711	669	1770
39	73	57.0	54	11.9	39.2	962	912	2894
44	73	66.8	61	12.9	43.9	1231	1178	4205
49	73	76.0	68	13.7	48.3	1514	1459	5662
54	73	84.6	75	14.4	52.3	1807	1752	7230
59	73	92.8	81	15.1	56.1	2107	2051	8879
64	69	96.1	83	15.8	59.7	2303	2249	10143

PERIODIC MORTALITY

PERIOD AGES INCLUSIVE	NO. TREES	BASAL AREA	AVG. DIA.	AVG. HT.	CUBIC VOLUME TOTAL	CUBIC VOLUME MERCH.	BD.FT. VOLUME
20 THRU 24	0	0.0	0.0	0.0	0	0	0
25 THRU 29	0	0.0	0.0	0.0	0	0	0
30 THRU 34	2	.8	8.5	26.1	10	9	12
35 THRU 39	0	0.0	0.0	0.0	0	0	0
40 THRU 44	0	0.0	0.0	0.0	0	0	0
45 THRU 49	0	0.0	0.0	0.0	0	0	0
50 THRU 54	0	0.0	0.0	0.0	0	0	0
55 THRU 59	0	0.0	0.0	0.0	0	0	0
60 THRU 64	4	4.6	14.5	56.0	103	100	416
TOTALS	6	5.3			113	109	428

TREES CUT IN THINNING

AGE	NUMBER TREES	BASAL AREA	AVG. DIA.	AVG. HT.	CUBIC VOLUME TOTAL	CUBIC VOLUME MERCH.	BD. FT. VOLUME	DISCOUNTED VALUE
19	117	11.3	4.1	17.4	118	57	0	$ 0.00
TOTALS	117	11.3			118	57	0	$ 0.00

INCREMENT AND FINANCIAL ASPECTS

AGE	MEAN ANN. INCREMENT CUBIC**	MEAN ANN. INCREMENT BD. FT.	DISCOUNTED VALUES	GROWTH PERCENT * TOTAL CU.	GROWTH PERCENT * BD.FT.
19	13.0	0	$ 0.00	0.0	0.0
19	6.8	0	$ 0.00	0.0	0.0
24	12.6	9	$ 13.48	16.1	0.0
29	17.1	31	$ 49.68	9.6	24.8
34	20.9	52	$ 85.23	7.1	13.2
39	24.7	74	$ 120.18	6.0	9.6
44	28.0	96	$ 150.63	4.9	7.4
49	30.9	116	$ 174.96	4.1	5.9
54	33.5	134	$ 192.70	3.5	4.9
59	35.7	150	$ 204.15	3.1	4.1
64	36.0	158	$ 201.17	1.8	2.7

* GROWTH PERCENT AT MIDDLE OF THE 5-YEAR PERIOD ENDING AT AGE SHOWN
** MEAN ANNUAL INCREMENT IS FOR TOTAL CUBIC VOLUME INCREMENT

SITE INDEX= 90
AGE SIMULATION STOPPED= 64
INTEREST RATE= 3 PERCENT
DISCOUNTED VALUE CALCULATED TO AGE SIMULATION STARTED
STUMPAGE VALUE CALCULATED AT 75 DOLLARS PER M
CUT 60 PERCENT OF TREES IN PRECOMMERCIAL THINNING
DONE

EXHIBIT 2

OCTOBER 5,1982
BEATTY CREEK STUDY,15X15 FOOT SPACING,PLOT 1
SCRIBNER BD. FT. VOL. ALL TREES 7.6 INCHES D.B.H. & UP TO A 5 INCH TOP
MERCHANTABLE CUBIC VOL. ALL TREES 5.6 INCHES D.B.H. & UP TO A 3 INCH TOP
MANAGED STAND MORTALITY
ALL VALUES PER ACRE BASIS

PROJECTED BASAL AREA AND VOLUME BY TREE SIZES AGE 19

	BASAL AREA	VOLUME CUBIC TOTAL	VOLUME CUBIC MERCH.	VOLUME BD.FT.	NUMBER TREES	AVERAGE HEIGHT
TREES LESS THAN 4.6 INCHES	10.4	108			117	17
TREES 4.6 TO 6.5	10.6	116	8		75	20
TREES 6.6 TO 8.5	0.0	0	0	0	0	0
TREES 8.6 TO 10.5	0.0	0	0	0	0	0
TREES 10.6 TO 12.5	0.0	0	0	0	0	0
TREES 12.6 TO 14.5	0.0	0	0	0	0	0
TREES 14.6 TO 16.5	0.0	0	0	0	0	0
TREES LARGER THAN 16.5	0.0	0	0	0	0	0
TOTALS OR AVERAGE	21.0	224	8	0	192	18

TREES CUT AT AGE 19

	BASAL AREA	VOLUME CUBIC TOTAL	VOLUME CUBIC MERCH.	VOLUME BD.FT.	NUMBER TREES	AVERAGE HEIGHT
TREES LESS THAN 4.6 INCHES	9.2	95			105	17
TREES 4.6 TO 6.5	1.5	16	0		12	19
TREES 6.6 TO 8.5	0.0	0	0	0	0	0
TREES 8.6 TO 10.5	0.0	0	0	0	0	0
TREES 10.6 TO 12.5	0.0	0	0	0	0	0
TREES 12.6 TO 14.5	0.0	0	0	0	0	0
TREES 14.6 TO 16.5	0.0	0	0	0	0	0
TREES LARGER THAN 16.5	0.0	0	0	0	0	0
TOTALS OR AVERAGE	10.6	111	0	0	117	18

PROJECTED BASAL AREA AND VOLUME BY TREE SIZES AGE 19

	BASAL AREA	VOLUME CUBIC TOTAL	VOLUME CUBIC MERCH.	VOLUME BD.FT.	NUMBER TREES	AVERAGE HEIGHT
TREES LESS THAN 4.6 INCHES	1.3	13			12	18
TREES 4.6 TO 6.5	9.1	100	8		63	20
TREES 6.6 TO 8.5	0.0	0	0	0	0	0
TREES 8.6 TO 10.5	0.0	0	0	0	0	0
TREES 10.6 TO 12.5	0.0	0	0	0	0	0
TREES 12.6 TO 14.5	0.0	0	0	0	0	0
TREES 14.6 TO 16.5	0.0	0	0	0	0	0
TREES LARGER THAN 16.5	0.0	0	0	0	0	0
TOTALS OR AVERAGE	10.3	113	8	0	75	20

PROJECTED MORTALITY AGE 20 THROUGH 24 INCLUSIVE

	BASAL AREA	VOLUME CUBIC TOTAL	VOLUME CUBIC MERCH.	VOLUME BD.FT.	NUMBER TREES	AVERAGE HEIGHT
TREES LESS THAN 4.6 INCHES	0.0	0			0	0
TREES 4.6 TO 6.5	0.0	0	0		0	0
TREES 6.6 TO 8.5	0.0	0	0	0	0	0
TREES 8.6 TO 10.5	0.0	0	0	0	0	0
TREES 10.6 TO 12.5	0.0	0	0	0	0	0
TREES 12.6 TO 14.5	0.0	0	0	0	0	0
TREES 14.6 TO 16.5	0.0	0	0	0	0	0
TREES LARGER THAN 16.5	0.0	0	0	0	0	0
TOTALS OR AVERAGE	0.0	0	0	0	0	0

PROJECTED BASAL AREA AND VOLUME BY TREE SIZES AGE 24

	BASAL AREA	VOLUME CUBIC TOTAL	VOLUME CUBIC MERCH.	VOLUME BD.FT.	NUMBER TREES	AVERAGE HEIGHT
TREES LESS THAN 4.6 INCHES	0.0	0			0	0
TREES 4.6 TO 6.5	2.4	27	26		12	20
TREES 6.6 TO 8.5	18.7	227	215	117	59	24
TREES 8.6 TO 10.5	1.8	23	21	34	4	27
TREES 10.6 TO 12.5	0.0	0	0	0	0	0
TREES 12.6 TO 14.5	0.0	0	0	0	0	0
TREES 14.6 TO 16.5	0.0	0	0	0	0	0
TREES LARGER THAN 16.5	0.0	0	0	0	0	0
TOTALS OR AVERAGE	22.9	277	262	151	75	23

Volume and Tree-Size Projection

Volumes are projected from estimates of gross cubic-volume increment for the stand. Height growth is obtained from curves that estimate site index and height growth described in an earlier paper (Dahms 1975). Stand increment is apportioned to an individual tree based on diameter and height of that tree relative to diameter and height of all trees on the plot. Diameter is calculated from the updated volume and height of the tree. Growth of each tree is simulated in this way a year at a time.

The equation for gross-volume increment was obtained from natural stands as described in earlier papers (Dahms 1964, 1975). The relation of volume increment in the managed stand to stand density was obtained from two levels-of-growing-stock studies and an initial spacing study.

The user has the option of using the volume increment in the natural stand or of increasing or decreasing it by a percentage if the particular use indicates a higher or lower growth rate is probable.

Thinning

The type of thinning built into the model has the small, weak, or diseased trees cut. The user specifies intensity of thinning as a percent of stems to be removed. Because a random element exists in selection of trees to be cut, percent specified is not always exactly achieved.

Flexibility in the kind of thinning desired can be achieved by combining a lower size limit with percent of trees to be cut. Even though the percent-of-cut equation will select small trees for cutting, an "If screen" returns trees below the specified size to the reserve stand.

Mortality

Five mortality options are available:

1. No mortality;
2. Managed-stand mortality;
3. Pringle Falls mortality;
4. North Idaho natural-stand mortality; or
5. Combined mortality.

The managed-stand mortality is based on a 15-year record for two central Oregon levels-of-growing-stock studies. Because thinning occurred at 5- to 10-year intervals, it represents losses at a fairly high intensity of management.

Pringle Falls mortality represents 32 years of records on three 1/2-acre plots — two thinned and one unthinned — in a stand that was heavily attacked by rust cankers. Mortality was heavy and mostly attributable to rust cankers caused by *Peridermium harknessii* J.P. Moor and *P. stalactiforme* Arth. and Kern. Deaths were spread fairly uniformly over the years of record.

The natural-stand mortality from north Idaho was taken from Hamilton and Edwards (1976). Combined mortality uses managed-stand mortality through age 59 and then goes to natural-stand mortality. The assumption is that older stands will suffer more mortality.

The mortality options presented leave much to be desired because possible management alternatives for reducing tree losses cannot be evaluated. For example, what effect will frequency of thinning have on number of trees lost between thinnings? Is mortality related to age or stand density? These are important questions when we think about desirable density regimes and culmination of mean annual increment Despite the shortcomings of the present mortality estimates, they are a start in the right direction and give foresters some idea of the range of mortality and of the kind of data needed to improve estimates.

None of the mortality estimates makes allowance for catastrophic losses, such as might occur from a major attack of mountain pine beetles. Recent information linking stand density to the susceptibility of lodgepole pine trees to mountain pine beetle attack (Mitchell et al. in press) means that by proper stand-density control, catastrophic outbreaks might be averted.

Measuring Stand Density

Crown competition factor[2] (C.C.F.) was chosen as the measure of stand density to be used with this lodgepole pine simulation model because a given C.C.F. comes close to representing a constant tree competition regardless of stand age, tree size, or site quality. The relation of C.C.F. to basal area shown in table 1 indicates that for a given C.C.F., basal area starts out small with small trees and rises rapidly with increasing tree size. As tree size increases, the rate of basal area increase slows.

A useful fact for those accustomed to thinking in terms of basal area is that for 10-inch trees, C.C.F. and basal area are so nearly the same that thinking of them as identical does not introduce a significant error (table 1).

C.C.F. compares growing space available to a tree with that represented by a vertical projection of the crown of the average open-grown tree of the same d.b.h. A C.C.F. of 100 means individual trees have, on the average, as much growing space as that represented by the crown of an open-grown tree. A C.C.F. of 200 means half as much space per tree as the open-grown tree-crown area, and a C.C.F. of 50 means twice as much.

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[2]Crown-competition factor is more fully described by Krajicek and others (1961).

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Table 1 — Basal area and number of trees per acre by size class for crown-competition factor (C.C.F.) values 60, 100, and 140

	Basal area			Trees		
Diameter	C.C.F. 60	C.C.F. 100	C.C.F. 140	C.C.F. 60	C.C.F. 100	C.C.F. 140
Inches	*Square feet*			*Number*		
2	19.5	32.5	45.4	893	1,488	2,083
4	36.4	60.6	84.8	417	694	972
6	47.1	78.7	110.1	240	401	561
8	54.5	90.8	127.4	156	260	365
10	60.0	99.8	139.6	110	183	256
12	63.6	106.0	148.4	81	135	189
14	66.3	111.2	156.1	62	104	146
16	69.8	115.9	162.0	50	83	116

Testing the Simulation Model

The simulation model was tested three ways:

1. Comparing actual and simulated performance on three plots from age 55 to 87 years and from plots on two levels-of-growing-stock studies over a shorter period.
2. Comparing gross and net yields for lodgepole pine and a comparison of this relation with that for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).
3. Comparing size distribution, average diameter, and total cubic volume between simulation estimates and actual plot values in some older stands.

The first comparison tested all aspects of the simulation model. Three plots is a small number, however, and 32 years is a short time for a comparison. Consequently, other ways to test the model were sought.

The gross-volume-increment equation can be tested by comparing gross yield, a cumulative total of gross increment, with net yield. Similar comparisons are available for ponderosa pine and Douglas-fir to form a basis for judging the comparison for lodgepole pine.

A third kind of test, aimed at comparing diameter distribution of simulated stands with actual ones, tests the volume-increment distribution to individual trees and, indirectly, height growth.

All three kinds of tests indicate the simulation model is producing estimates close to actual stand performance. Actual comparisons are covered in much greater detail in the Appendix.

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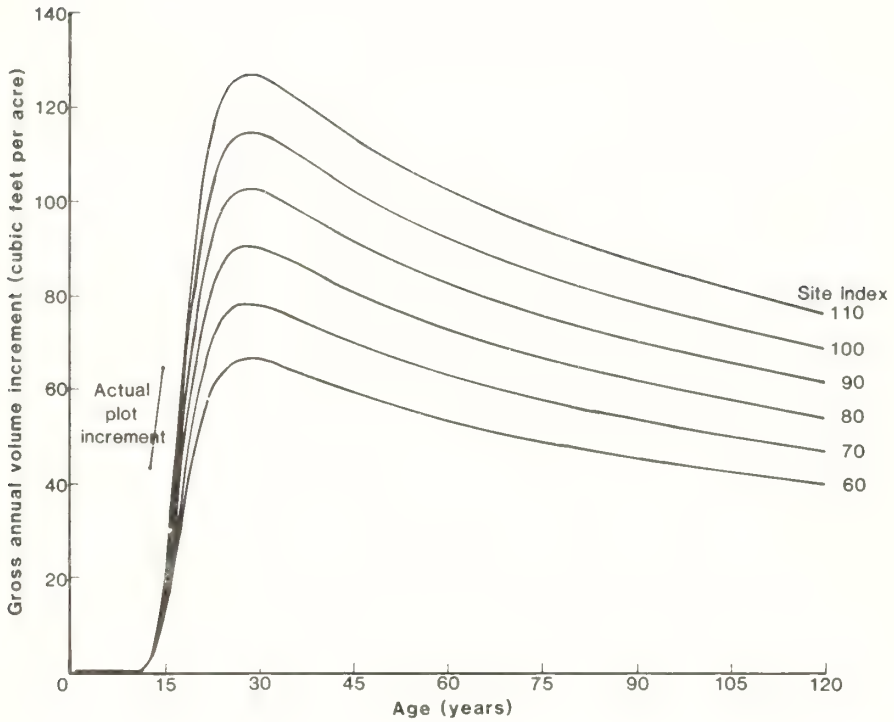


Figure 1. — Gross-increment equation before adjusting the extrapolated portion between age 0 and 25 years. Values presented are for the average density found on the gross-yield plots.

The Gross-Increment Equation

The gross-increment equation is one of the basic parts of the lodgepole pine simulation model. It was fit to gross-increment data from 94 temporary plots established in natural stands on the eastern slope of the Cascade Range, between Crater Lake National Park in the south and Bend in the north. The relation of stand density to volume increment was derived from data obtained from two levels-of-growing-stock studies and a spacing study.

The equation for gross-volume increment has evolved over the years. The first equation,

Annual cubic volume increment per acre = 1.42 - .0439 (C.C.F.) + .01109 (C.C.F. × site index) - .003366 (site index × age),

was part of the gross and net yield tables for lodgepole pine (Dahms 1964). The second,

Log_e volume increment = 8.77295 - 1.5877 × (Log_e C.C.F.) + 1.07996 × (Log_e site index) - 3.32686 × (Log_e age) + .599002 × (Log_e age × Log_e C.C.F.),

where C.C.F. = 176.3 - .2407 × age, was part of a general assembly of information on lodgepole pine (Dahms 1975). Both of these equations covered the age range of the data from 25 to 120 years and relied on the relation of volume increment to stand density found in natural stands.

The latest version of the equation has been extrapolated to include the age range from 0 to 25 years. The first attempt is shown as figure 1. This equation is of the form

Log_e volume increment = A + B × $(1 - e^{-K \times \text{age}})$ - K × Log age;

where A is a function of site index and B is a function of both C.C.F. (stand density) and site index.

The extrapolated portion of the equation is definitely bounded by almost zero at the time the stand reaches breast height and known values at age 25 years. Two tests were applied to check reasonableness of the extrapolated portion of the equation:

1. A cumulative summary of increment from the gross-increment equation should exceed net yield to age 25 years.
2. Increment from two plots with trees spaced at 6 × 6 feet[3] was available for comparison.

A comparison of increment on the two permanent sample plots as shown in figure 1 indicates increment started faster on the plots than the extrapolated equation shows. Similarly, the comparison of a cumulative summary of increment from the gross-increment equation with net yield to age 25 showed net yield to be greater. Clearly, the extrapolated growth rate needed to be increased.

[3]The Beatty Creek spacing study was installed in a dense stand of lodgepole pine seedlings, mostly 4 years old, that came in after the 1960 Anthony Lakes burn. Elevation is about 5,800 feet and site index about 90 feet. Soil is a tolo silt loam with 1 to 2 feet of ash overlying a silt loam to clay loam buried soil. Spacings represented were 6 × 6 feet, 9 × 9, 12 × 12, 15 × 15, and 18 × 18. Excess trees were pulled up by hand. Only an occasional tree had to be transplanted to achieve the desired spacing. Increment figures for the two 6 × 6-feet plots were for midperiod ages 12.5 and 14.5 years.

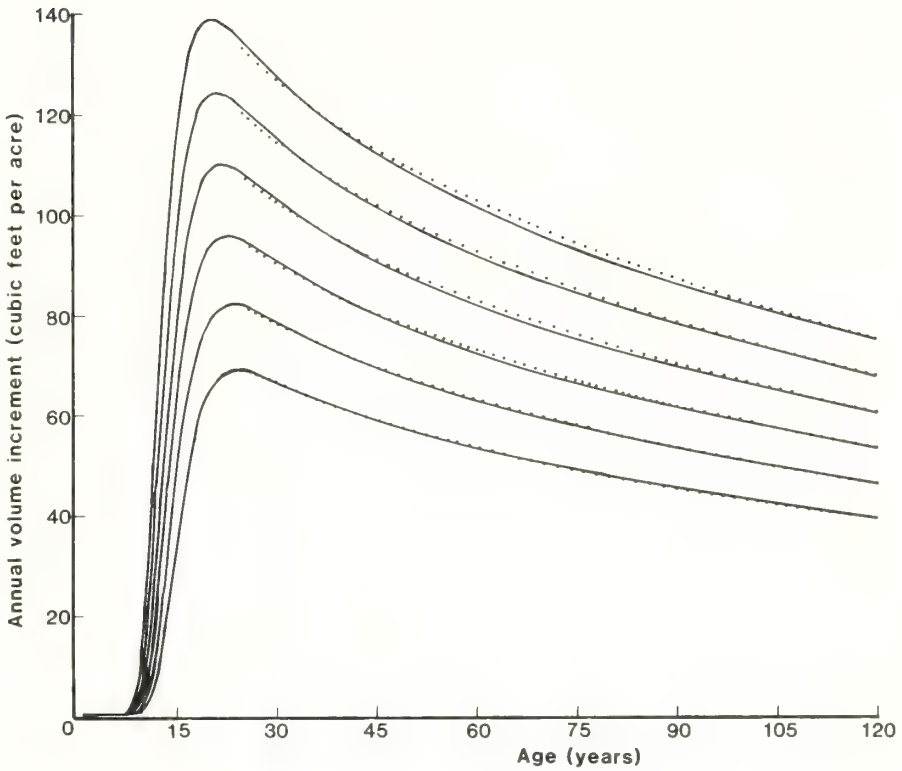


Figure 2. — A comparison of an earlier linear logarithmic volume-increment equation (dotted) with the present equation including the extrapolated portion (solid).

To increase the early growth rate indicated by the equation,

$$\text{Log volume increment} = A + B \times (1 - e^{-K \times \text{age}}) - K \text{ Log age},$$

the coefficient K was split into two coefficients to give an equation of the form

$$\text{Log}_e \text{ volume increment} = A + B \times (1 - e^{-K1 \times \text{age}}) - K \times \text{Log age}.$$

The coefficient K1 was adjusted to produce the result shown as figure 2. This equation does match the growth in permanent sample plots quite well, and also the cumulative-increment summary compares well with net yield, as will be shown later. As more data become available from Beatty Creek and other spacing studies, the equation can be improved.

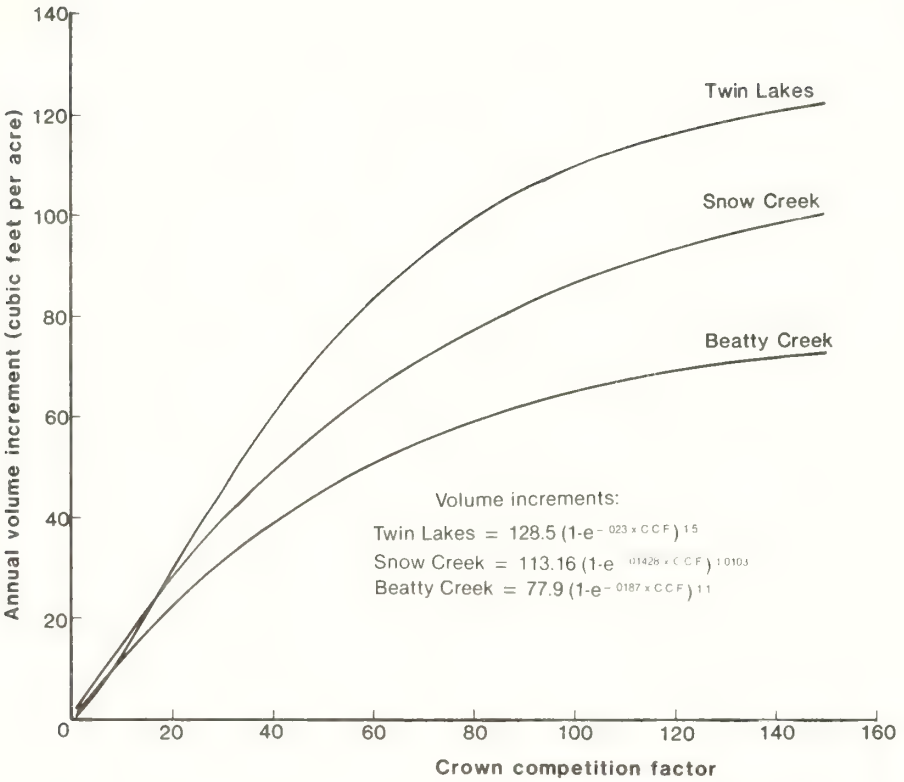
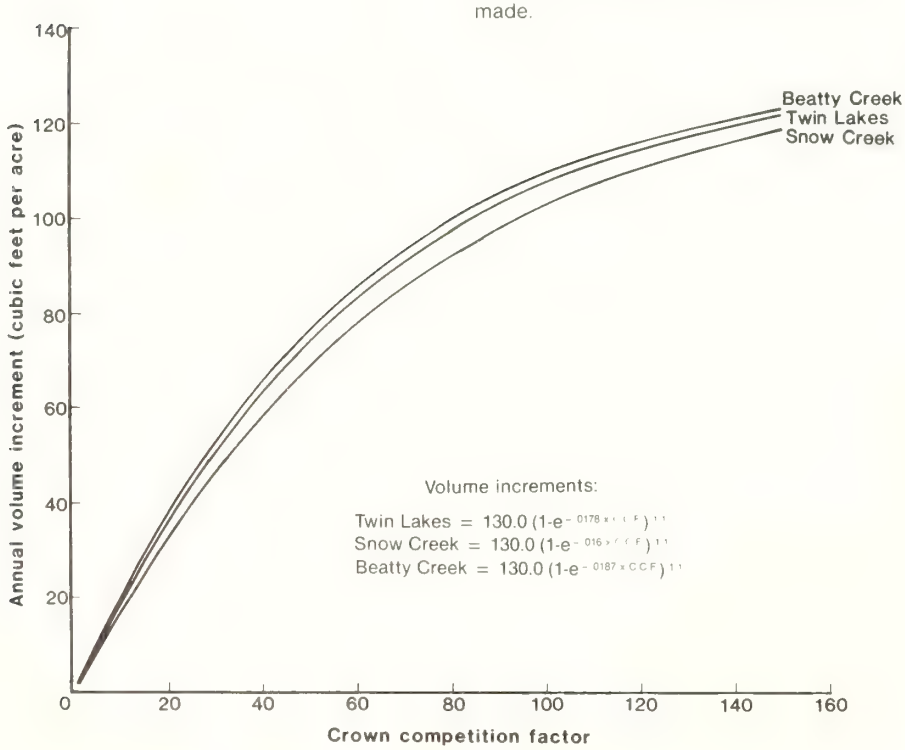


Figure 3. — Comparison of volume increment over stand density (C.C.F.) curves at Twin Lakes, Snow Creek, and Beatty Creek before any adjustments were made.



Introducing the Relation of Stand Density to Volume Increment

Introducing the relation of average stand density to volume increment that was found on two levels-of-growing-stock studies and a spacing study was the final step in fitting the gross-increment equation. This relationship from the two studies was more desirable than that found in the natural stands sampled by the gross-increment plots because:

1. The levels-of-growing-stock study estimate seemed a much better estimate of managed-stand performance.[4]
2. The levels-of-growing-stock and spacing studies had plots at very low densities, as well as higher ones. The natural stand plots did not cover the low-density end of the range.

Data from the two levels-of-growing-stock studies and one spacing study were available. The Twin Lakes study (described more fully in Dahms 1971b) is in a young stand that averaged 35 years old during the latest growth period and is growing on a very good site. The Snow Creek study (see Dahms 1973) averaged 59 years of age during the latest growth period and is growing on a medium site. Both of these studies are located on pumice soil in central Oregon. Trees of the Beatty Creek spacing study (see footnote 3) averaged 14.5 years during the latest growth period and are growing on a near-average site in the Blue Mountains.

[4] Stand density and site quality almost inevitably become confounded where widely scattered single plots are used, so that site index is the only measure of site quality. In the levels-of-growing-stock studies, site quality is held essentially constant with only stand density varying. Small, unintentional variations in site quality show up as slightly increased variation

Figure 4. — Volume increment as a function of stand density (C.C.F.) at Beatty Creek, Twin Lakes, and Snow Creek with common N1 and B values to compare shape of curves.

The curves of volume increment over stand density for the latest growth period available at the Twin Lakes and Snow Creek levels-of-growing-stock studies, and the Beatty Creek spacing study, as shown in figure 3, have generally similar shapes. Equations for the three studies are:

Beatty Creek spacing

Volume increment
$= 77.9\ (1 - e^{-.0187 \times C.C.F.})^{1.1}$

Twin Lakes levels-of-growing-stock

Volume increment
$= 128.5\ (1 - e^{-.023 \times C.C.F.})^{1.5}$

Snow Creek levels-of-growing-stock

Volume increment
$= 113.2\ (1 - e^{-.01428 \times C.C.F.})^{1.0103}$

These equations are all of the form

Volume increment
$= B\ (1 - e^{-K \times C.C.F.})^{N}$

The coefficient B controls the ultimate height of the curve and is therefore related to site quality and stand age The coefficients K and N control the shape of the curves.

The shape of these curves can best be compared if B, or the ultimate height, is held constant as in figure 4. The shapes are quite similar except the Twin Lakes one has a peculiar shape at the very low end, where adding more density causes volume increment to climb more slowly there than for the other two studies. This peculiarity seems hard to explain in biological terms and is therefore treated as a peculiarity of the data.

To make the curves more nearly the same shape and to see if any trends occur with age, an average N coefficient of 1.1 was used, and new equations, as shown in figure 5, were calculated. This change produced a more biologically logical shape for the Twin Lakes curve. It also brought out a gradual flattening of the curve, or slowing of the rise in volume increment with increasing stand density with greater age. Final curves of volume increment over stand density for each study are shown as figure 5.

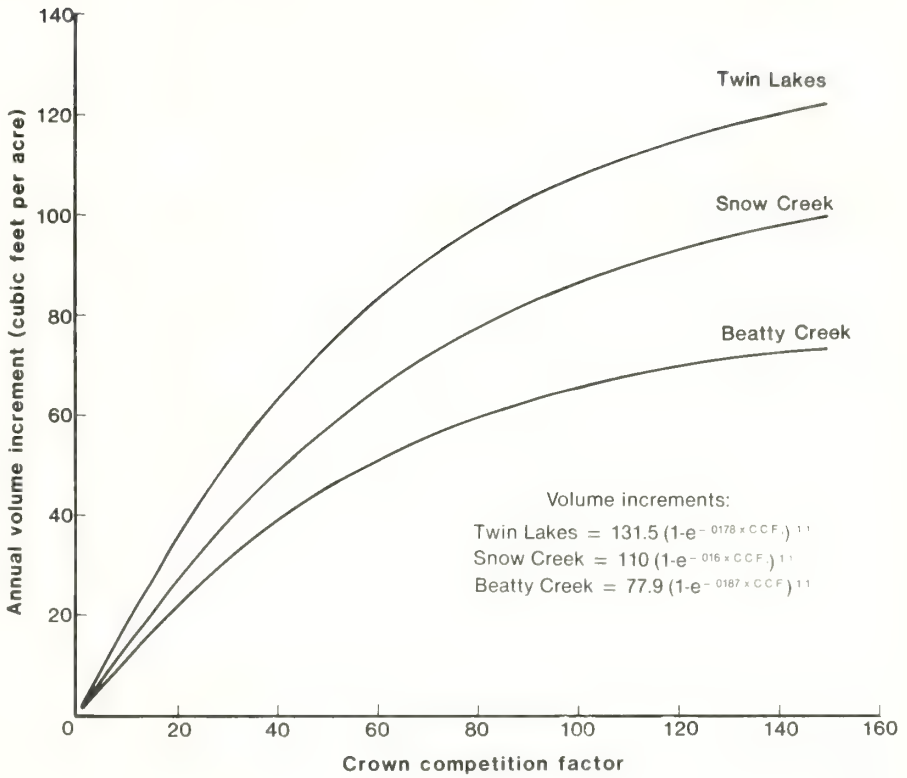


Figure 5. — Volume increment as a function of stand density (C.C.F.) at Twin Lakes, Snow Creek, and Beatty Creek.

Restricting the N value to 1.1 for all curves reduced percent of variation accounted for by stand density at Twin Lakes from .8658 to .8607 and left the percentages unchanged at .9291 at Snow Creek and .9822 at Beatty Creek, an almost insignificant loss of fit.

To accept the flattening trend of the curves with increasing age solely on the basis of the present three studies might be considered unwarranted. A similar trend showed up in the linear logarithmic equation that was fit to the natural-stand gross yield plots, however, and Assman (1970) describes such a change with age in the shape of curves of volume increment over stand density in German studies. Therefore, the trend was accepted as real.

The relation of volume increment to stand density shown by the levels-of-growing-stock and spacing studies does not get into the high-density area where volume increment begins to decline with increasing density. Ideally, this part of the density range should be covered, but lack of these kinds of data should not be critical in estimating results of possible manipulations of managed stands. Those who operate the simulator should not go much beyond C.C.F. 200.

The final gross-increment equation together with a linear logarithmic equation fit to the gross-yield plot data are shown as figure 2. Note the very close resemblance of the two equations from age 25 on. The relation of volume increment to stand density taken from the levels-of-growing-stock and spacing studies was fitted into the gross-increment equation so that volume increment was the same for managed stands and natural stands at the average-stand density for natural stands represented by the equation

C.C.F. = 176.3 - .2407 × age.

The equations of figures 1 and 2 both represent the relation of volume increment to age at the average stand density found on plots in the natural stands. Although none of the plots were thinned, if one stand were to follow the stand-density regime specified, a thinning would have to be made every year.

Estimating Growth of Individual Trees

Individual tree-growth estimates are obtained each year by allocating a portion of total plot increment to each tree, getting an updated height from the height-growth or site-index estimating curves, and then with height and volume known, solving the volume equation for diameter.

Stand or plot-volume increment is allocated to individual trees on the basis of the proportion

$$\frac{\text{Tree volume increment}}{\text{Plot volume increment}} = \frac{\text{Tree } D^{1.818} \times H^{1.786}}{\Sigma(\text{Tree } D^{1.818} \times H^{1.786})}$$

The particular power of diameter and height were derived from permanent sample-plot data, where diameter and height of each tree had been measured each 5 years. Tree-volume increment and total plot-volume increment were calculated from tree diameter and height and a local volume equation. The sum of squares of (tree percent of plot-volume increment - estimated tree percent)^2 was then minimized by iteration with different powers of diameter and height until the best combination was found. Trees on the levels-of-growing-stock plots were used to fit the tree-increment proportion equation. Trees ranged in size from 3 inches in diameter 20-feet tall to 13-inch 60 footers.

Height of the tallest tree per 1/5 acre is obtained from curves for estimating site index or height growth. If the stand is 20 years old or less, height-growth curves are used. If the stand is older, site-index estimating curves are used. These curves have a 100-year index age. They are more fully described in Dahms (1975).

To go from height of the tallest tree or trees to height of lesser trees, height is expressed as a percentage of the tallest at the start. This percentage is used through the years in the simulation process.

The assumption that relative height of trees remains the same is not entirely true (Dahms 1963); however, future height is almost certainly more closely related to past height than to diameter.

Mortality

Two unlike sources of mortality data were available for central Oregon lodgepole pine. The first was two levels-of-growing-stock studies, one at Twin Lakes (see Dahms 1971b) that was 22 years old at the time the study was installed and the other at Snow Creek (see Dahms 1973), 47 years old. For both studies, a 15-year record of growth and mortality was available. The stands are considered healthy, but some rust cankers were present in both. Thinning discriminated heavily against cankered trees, however.

The second source of mortality data was a thinning study of three plots installed in a 55-year-old stand at the Pringle Falls Experimental Forest. Two of the plots were thinned, one heavily and the other moderately; the third was left unthinned. The stand was so heavily infected with rust cankers caused by *Peridermium harknessii* and *P. stalactiforme* that Beeman[5/] reported 67 percent of the reserve trees on the thinned plots were infected.

Mortality from the levels-of-growing-stock studies represents what might be expected in a healthy managed stand. The Pringle Falls results are an example of the kind of mortality that can occur in a stand heavily infected with rust cankers.

[5/] Beeman's unpublished report is quoted in Dahms (1971a). The original report was burned in the 1974 Silviculture Laboratory fire.

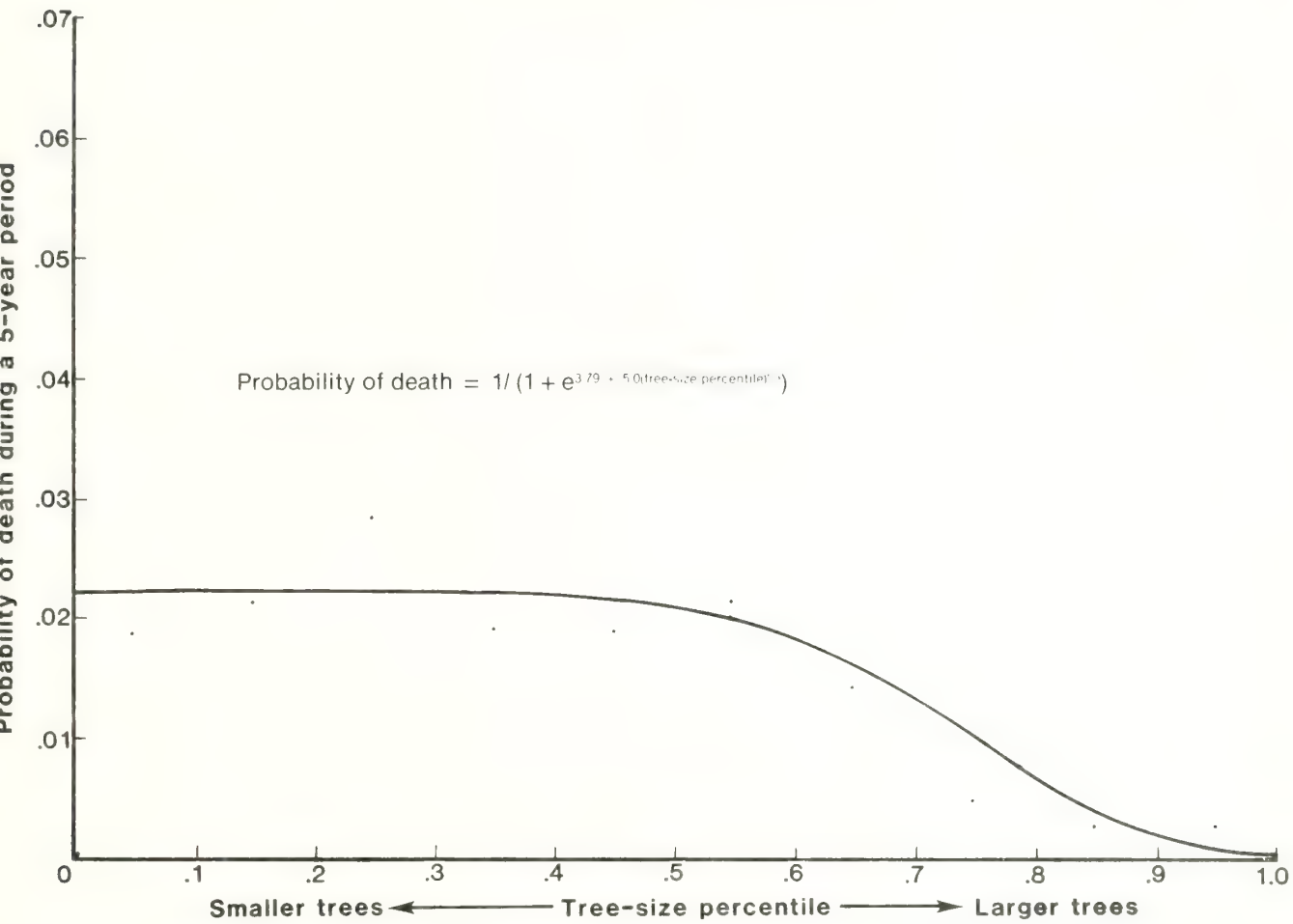


Figure 6. — Probability of a tree dying during a 5-year period as related to tree-size percentile at Snow Creek and Twin Lakes — the managed-stand option.

To express mortality as a probability of death in an equation for any given tree to use in a computer simulation model, we borrowed some ideas from Hamilton (1974) and Hamilton and Edwards (1976). The equation form chosen was

$$\text{Probability of death} = 1/(1 + e^{(A + B\ (\text{tree-size percentile})^N)}).$$

To fit this equation, trees at the start of the 5-year period in question were ordered by size from smallest to largest. They were then divided into 10 groups as nearly equal as possible. The number of trees that died during the period was determined for each tree-size percentile group. An average probability of death for any given tree in any given tree-size percentile group could then be calculated.

The process for tree-size percentile grouping started out plot by plot for each period for the levels-of-growing-stock study data, but all were eventually added together for all periods and for all plots at both locations. The graph of figure 6 shows the relation of probability of death to tree-size percentile. The equation

$$\text{Probability of death} = 1/(1 + e^{(3.79 + 5.0\ (\text{tree-size percentile})^{5.3})})$$

accounted for 89 percent of the variation in probability of death. A chi-square test also confirmed the significance of the relation of tree-size percentile to probability of death, with the smaller trees more likely to die. This is the mortality obtained if the "managed stand" mortality option is selected.

An attempt was made to fit the same kind of equation to the Pringle Falls data, but no relation to tree size was found. Consequently, one average probability of death was used regardless of tree size.

To convert the 32-year mortality record to a probability of death for a given tree for a 1-year period, the compound-interest formula was used as described by Hamilton and Edwards (1976).

Probability of death for a given tree during a 1-year period over the 32 years averaged .01414 for the heavily thinned plot, .012703 for the moderately thinned one, and .01958 for the unthinned area. Average probability for all plots during a 1-year period was .01675, a figure heavily weighted in favor of the unthinned plot because it had many more trees on it. The average for all plots is the probability called when "Pringle Falls" mortality is selected. "Pringle Falls" mortality is about 4 times that of the "managed-stand" option and 2½ times the north Idaho or natural-stand option.

A combination of the "managed-stand" mortality for young stands and "natural-stand" mortality for older ones, provides what seems like a reasonable estimate of mortality for many stands. Such an estimate is available if the "combined-mortality" estimate is called. "Managed-stand" mortality is used to age 60; thereafter, "natural-stand" mortality is substituted.

Thinning

The probability that a given tree will be cut has been treated very much like the probability that a given tree will die. Because thinning was from below, smaller trees were much more likely to be cut than larger ones.

Equations expressing probability of cut as a function of tree-size percentile were fitted to individual-plot data from the Twin Lakes and Snow Creek levels-of-growing-stock studies previously described. The equation shown as figure 7 indicates about half of the trees were cut. All of the smallest trees were removed by thinning. In the zone between the .3 to .7 tree-size percentile, probability of cutting a tree drops rapidly as size increases until the probability of trees larger than the .7 percentile being removed is very small. This equation fit the data well, with tree-size percentile accounting for 97 percent of the variation in probability of cut.

To fit equations like the one shown in figure 7 to cut and leave data for a given plot, all trees are arrayed in order of diameter from the smallest to the largest. Trees are then divided into about 10 groups of as nearly equal size as possible. Number of groups can be adjusted somewhat to aid in keeping all groups the same size. For each group, a probability of cut is calculated by dividing number cut by total number of trees in the group. An equation of the form

$$\text{Probability of cut} = e^{-K(\text{tree-size percentile})N}$$

is fit. An iteration approach is required to obtain the best fitting K and N coefficients. The equation form is well suited to dealing with probability because it can only assume values between 0 and 1.

To make the probability of cut equations useful in the simulation model, a family of curves like that shown in figure 8 is needed. Data from thinnings at Twin Lakes and Snow Creek levels-of-growing-stock studies provided the basis for the curves of figure 8. Equations like that shown as figure 7 were fitted to plots covering a wide range of cut intensities. Equations expressing the coefficients K and N as functions of percent cut provide the basis for the required curve family that permits the simulator user to obtain any percent of cut desired.

Percent of cut specified is not always exactly achieved, partly because the choice of trees to be cut contains a random element. This effect can be averaged out by making several runs with a different random number start each time. Failure of equations to fit perfectly also causes some discrepancy between percent cut specified and result achieved by the simulator. This discrepancy is small, however.

Tree size combined with vigor and spacing were the main criteria for selecting trees to be cut at Twin Lakes. The family of curves shown as figure 8 depicts primarily the size-spacing effect. Thinning in stands where trees were infected with rust cankers or other diseases tends to show less correlation between relative tree size and probability of cutting.

A probability-of-cut equation can easily be developed for specific stands and marking rules by marking cut and leave trees with paper tags. Access to some kind of computer is needed to fit the equations.

Tree-Volume Equations

Total cubic-foot volume per tree inside bark including stump and tip was the starting point for all volume estimates. Board-foot volumes and merchantable cubic-foot volumes were obtained from total cubic-foot volume.

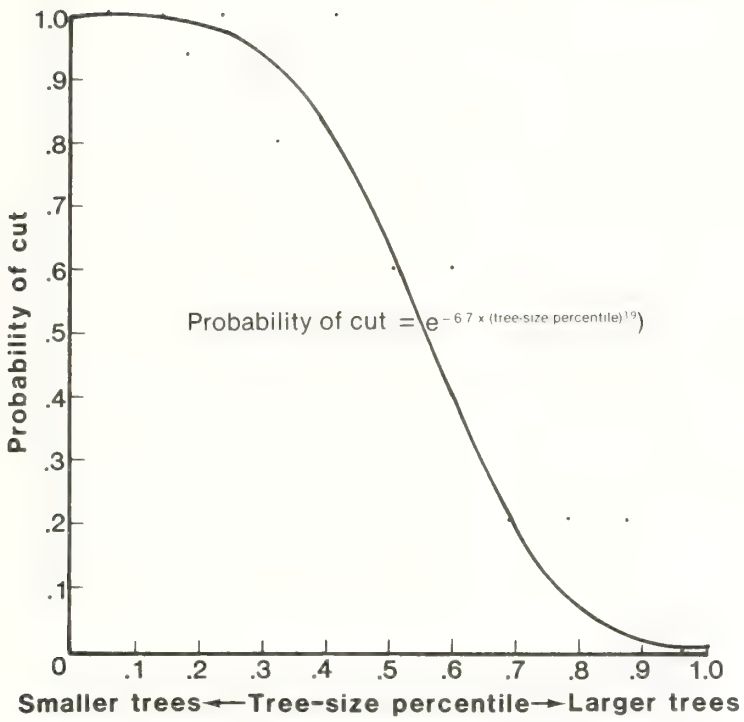


Figure 7. — Probability of a tree being cut as related to tree-size percentile. Twin Lakes plot number 1, 1964 thinning.

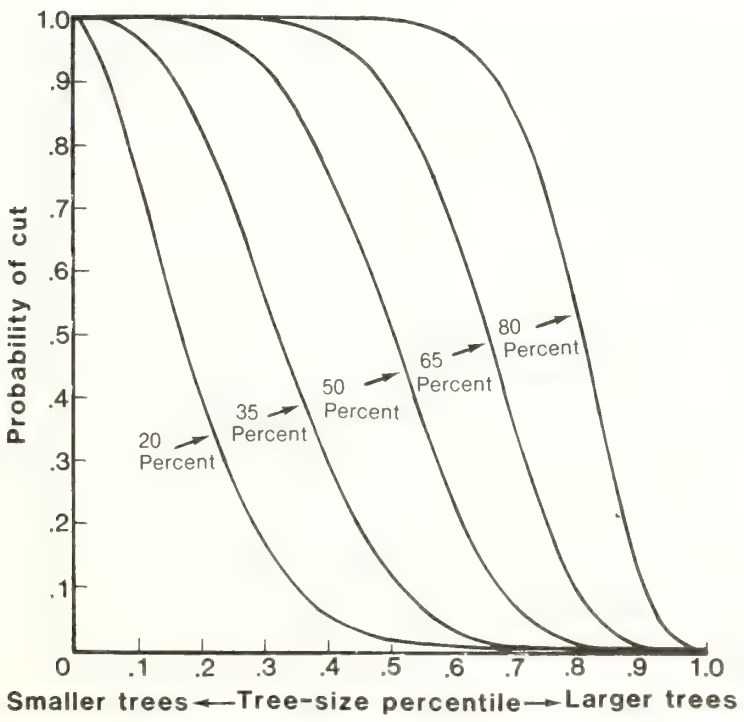


Figure 8. — Family of curves of probability of cutting a tree over tree-size percentile. Each curve results in a different percent of trees cut.

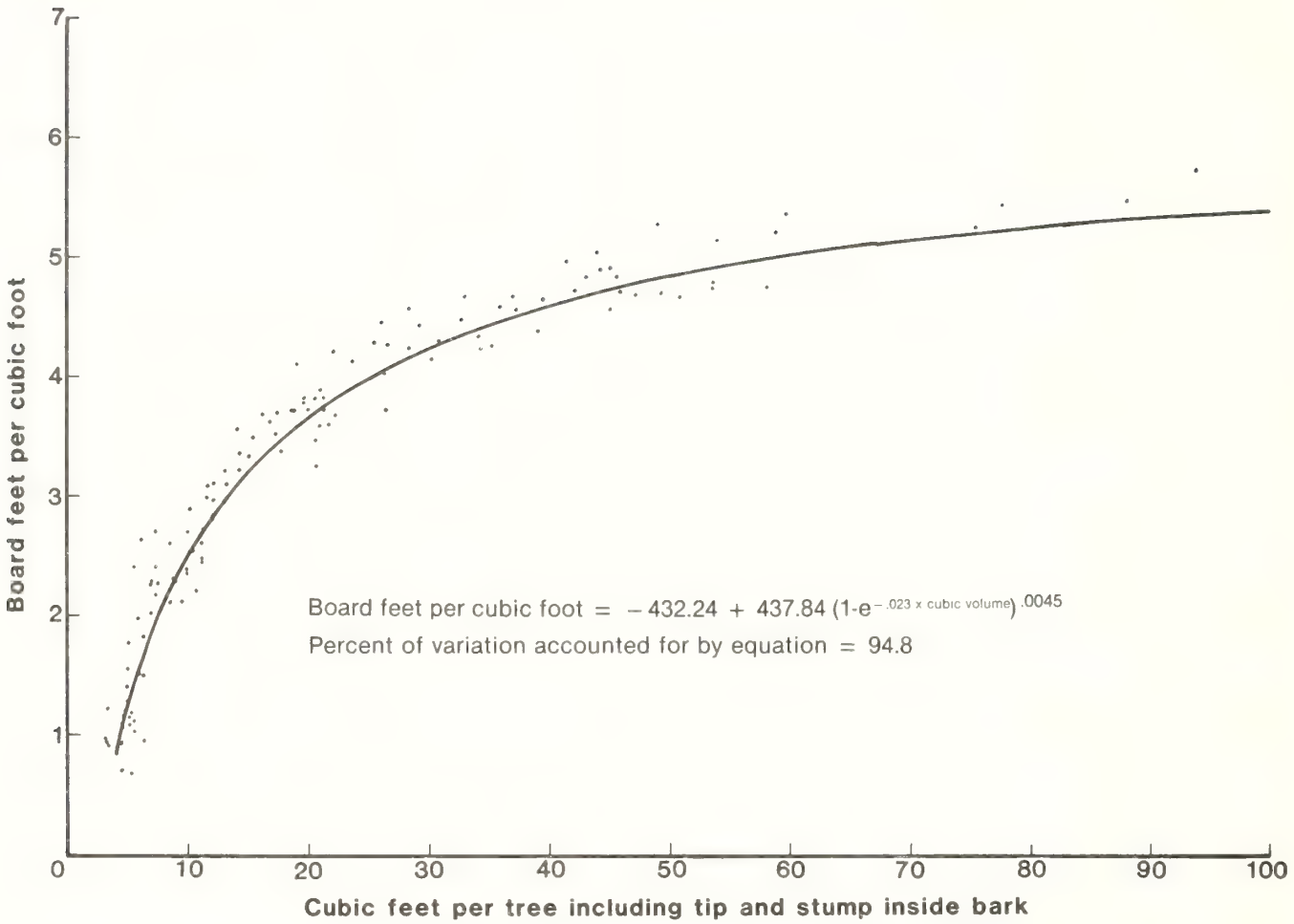


Figure 9. — Scribner board feet per cubic foot to a 5.0-inch top as a function of cubic-foot volume per tree.

Cylindrical form class volume equations of the type developed by Bruce and DeMars (1974) were used to estimate total stem volume of individual trees. The equation,

$$\text{Form} = .2539 - .5960/D + .0239\,(H/D) + 4.8422/H + 30.4688/H^2,$$

was fitted to data for 194 trees felled and cut up as a part of the central Oregon gross-yield study (Dahms 1964). Volume was calculated from the equation

$$\text{Volume} = F \times D^2 \times .005454154 \times H$$

where F = cylindrical form factor, D = d.b.h. outside bark in inches, H= total tree height in feet, and volume = total cubic stem volume inside bark including stump and tip.

To help those unfamiliar with this equation to visualize it, the expression $D^2 \times .005454154 \times H$ is the volume of a cylinder, in cubic feet, with length equal to height of the tree and diameter equal to tree diameter breast high outside bark. F is the portion of this cylinder occupied by wood inside bark.

Board-foot estimates were obtained from board feet per cubic foot ratios. The equation

$$\text{Scribner board feet to a 5.0-inch top} = -432.24 + 437.84\,(1 - e^{-.023 \times \text{cubic volume}})^{.0045},$$

together with the values used to derive the equation, are shown graphically as figure 9. The equation fits the data points well, accounting for 94.8 percent of the variation in board feet per cubic foot.

ght equations of this general form
ere fit, one for each log rule to a 5.0-,
0-, 7.0-, and 8.0-inch top. For the
ternational log rule, the four equa-
ons for board feet per cubic foot were:

o a 5.0-inch top = -3.35 + 9.21
- e $^{-.056 \text{ cubic volume}}$).3

o a 6.0-inch top = -76.25 + 82.025
-e $^{-.055 \text{ cubic volume}}$).035

o a 7.0-inch top = -9.02 + 14.82
- e $^{-.06 \text{ cubic volume}}$).31

o an 8.0-inch top = -1.26 + 7.135
- e $^{-.066 \text{ cubic volume}}$)1.3

or the Scribner log rule, the equations
ere:

o a 5.0-inch top = -432.24 + 437.84
-e $^{-.023 \text{ cubic volume}}$).0045

o a 6.0-inch top = -448.85 + 454.42
-e $^{-.025 \text{ cubic volume}}$).0046

o a 7.0-inch top = -55.05 + 60.49
- e $^{-.035 \text{ cubic volume}}$).049

o an 8.0-inch top = -494.21 + 499.69
- e $^{-.0345 \text{ cubic volume}}$).007

ercentage of variation in board feet
er cubic foot accounted for ranges
om 88.0 for the International board
et to a 6.0-inch top to 94.9 percent for
e Scribner board-foot equation to a
0-inch top. Board feet per cubic foot
strongly correlated with tree size, and
e equations describe the relationship
ell.

ny given tree size always has more
ternational board feet per cubic foot
an Scribner. This is more pronounc-
d for smaller trees than larger. Also,
e particular merchantable top used
as more effect on International board-
ot volume than Scribner (fig. 10,
ble 2). Because tree size is indicated
terms of average stand diameter in
ble 3 instead of total cubic volume as
figure 9, studying both the table and
e figure helps produce a better
ental image of the relationships.

Merchantable cubic volumes to a 3.0-, 4.0-, or 5.0-inch top were derived from total cubic volume. The three equations for merchantable cubic volume were:

To a 3.0-inch top in cubic feet = .49 + 422.33 (1 - $e^{-.003 \times \text{total cubic volume}}$)1.097.

To a 4.0-inch top in cubic feet = -.29 + 598.18 (1 - $e^{-.00198 \times \text{total cubic volume}}$)1.059.

To a 5.0-inch top in cubic feet = -1.68 + 11948.3 (1 - $e^{-.00008 \times \text{total cubic volume}}$).992.

These equations all accounted for 99.9 percent of the variation in merchantable cubic volume. Despite the very high R-square values, the equation expressing merchantable cubic volume to a 3.0-inch top shows slightly more merchantable volume than total for trees with less than 3 cubic feet. Because the error is small and few such trees are dealt with, this problem is not serious.

The total cubic-foot volume used was total stem volume inside bark including stump and tip. Board-foot and merchantable cubic volume were both for that portion of the stem above the stump, as cut, to the specified top diameter. Stumps ranged from 0.1 to 0.9 foot in height and averaged .43 foot. Because higher stumps tended to be left on larger trees, the average stump for trees of board-foot size was probably slightly higher than .43 foot.

Testing the Simulation Model

Three approaches to testing the simulation model were taken:

1. A comparison of predicted and actual performance on three Pringle Falls plots over a 32-year period and from plots on two levels-of-growing-stock studies over a shorter period of time.
2. A comparison of gross and net yields with gross yield representing a cumulative total of gross increment.
3. A comparison of predicted and actual diameter distribution, total net volume, and average diameter for some older gross-increment plots.

If enough plots with long periods of measured growth were available, only the first approach would have been used, but such plots do not exist.

Comparison With Permanent Sample Plots

Two sets of simulation runs were made to compare actual performance on the Pringle Falls plots with that estimated by the simulator. Simulation started with the stand as it existed at age 55 years, after thinning had taken place. In one trial, a mortality calculated for each plot was used in the simulator, but in the other, "combined mortality" was used.

Estimated net-volume increment was substantially below actual when mortality estimates developed for each plot were used (table 3). Estimates were 65, 56, and 62 percent of actual net increment for plots 11, 12, and 13, respectively. Average diameter too was underestimated.

Gross-volume increment also was underestimated, but because mortality was such a large part of it, the underestimate was not so large in terms of percent. Estimated gross-volume increment amounted to 76, 71, and 83 percent of actual gross increment for plots 11, 12, and 13, respectively.

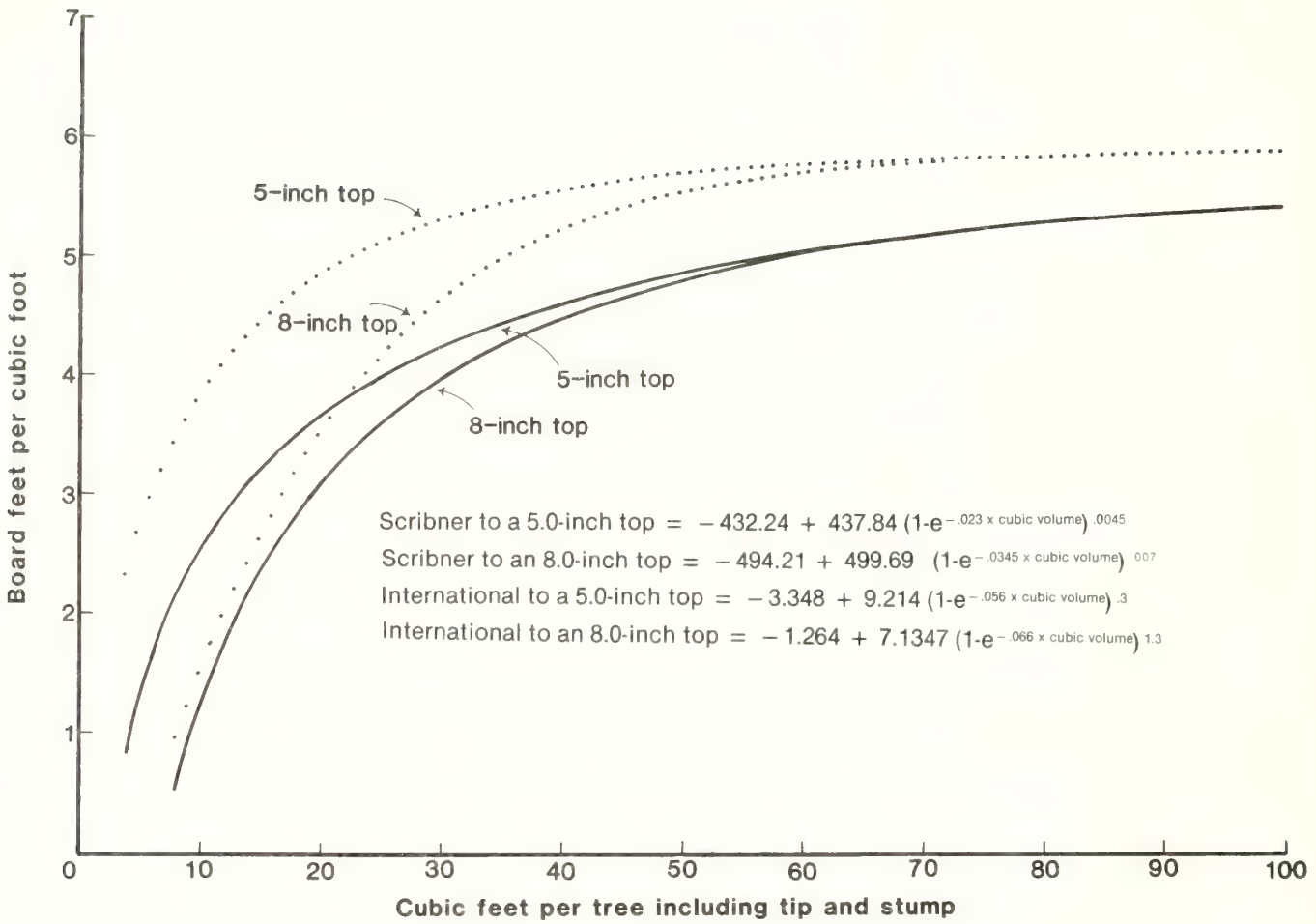


Figure 10. — Board feet per cubic foot International (dotted) and Scribner (solid), as a function of cubic feet per tree. Both rules to 5.0- and 8.0-inch tops.

Table 2 — Comparison between Scribner and International board-foot volumes to 5.0- and 8.0-inch tops at stand average diameters of 11.6 and 15.8 inches[1]

Stand average diameters	Scribner volume		International volume	
	5.0-inch top	8.0-inch top	5.0-inch top	8.0-inch top
Inches	.....	*Board feet*	.....	.....
11.6	10,787	9,099	14,167	10,539
15.8	24,889	24,115	28,745	27,232

[1] The stand had 166 trees at age 63 years when the average diameter was 11.6 inches, but mortality had reduced the number to 111 trees at 118 years when the average diameter was 15.8 inches.

eaking the total 32-year growth
riod into six 5-year measurement
riods and one 7-year period provides
ore insight into possible reasons for
e greater actual than estimated wood
oduction (table 4). Gross-volume
crement increased substantially
ring the third and fourth measure-
ent periods, exceeding that during
e first measurement period despite
creasing age, especially on plot 12.

ne trend of volume increment with
e on the unthinned plot is more in
e with the usual expectation, a fairly
eady decrease with increasing age.
me increase occurred during the
rd and fourth periods, but the rise
as not nearly as great as that on the
nned plots.

timated net-volume increment came
ry close to actual for the two thinned
ots when combined mortality was
ed (table 5). Estimated far exceeded
tual increment for the unthinned
ot, however.

tual mortality substantially exceeded
at estimated by the combined
ortality equation. On the unthinned
ot, only 338 of the original 640 trees
r acre were alive at the end of the 32-
ar period (table 5). By the combined
ortality equation, 527 trees were
timated to be alive.

tual mortality greatly exceeded
timated. The Pringle Falls plots are
cated in a pocket where a high
rcentage of trees were infected with
st cankers. No equation designed to
timate mortality over a broad area
uld be expected to fit such a small
ea. If a mortality equation were based
individual tree attributes including
st cankers, however, it probably
uld.

Table 3 — Comparison of actual and estimated diameter distribution, average diameter, and net-volume increment (all values per acre) for Pringle Falls lodgepole pine plots 11, 12, and 13 after 32 years of growth (estimates using Pringle Falls mortality)

Item	Plot 11		Plot 12		Plot 13	
	Actual	Estimate	Actual	Estimate	Actual	Estimate
Diameter class, inches:	*Number of trees*					
4.5 and less	0	2	0	0	60	94
4.6-6.5	6	9	4	27	96	96
6.6-8.5	10	22	56	72	70	72
8.6-10.5	24	27	68	43	80	40
10.6-12.5	38	18	38	16	26	20
12.6-14.5	18	12	26	16	6	10
14.6-16.5	6	4	4	6	0	3
16.6 and up	2	6	2	8	0	4
Total	104	100	198	188	338	339
	Inches					
Average diameter	11.0	10.1	10.0	9.2	7.1	6.9
	Cubic feet					
Annual net-volume increment	35.8	23.4	50.6	28.4	21.3	13.4

Table 4 — Gross periodic cubic increment[1] per acre, Pringle Falls plots 11, 12, and 13

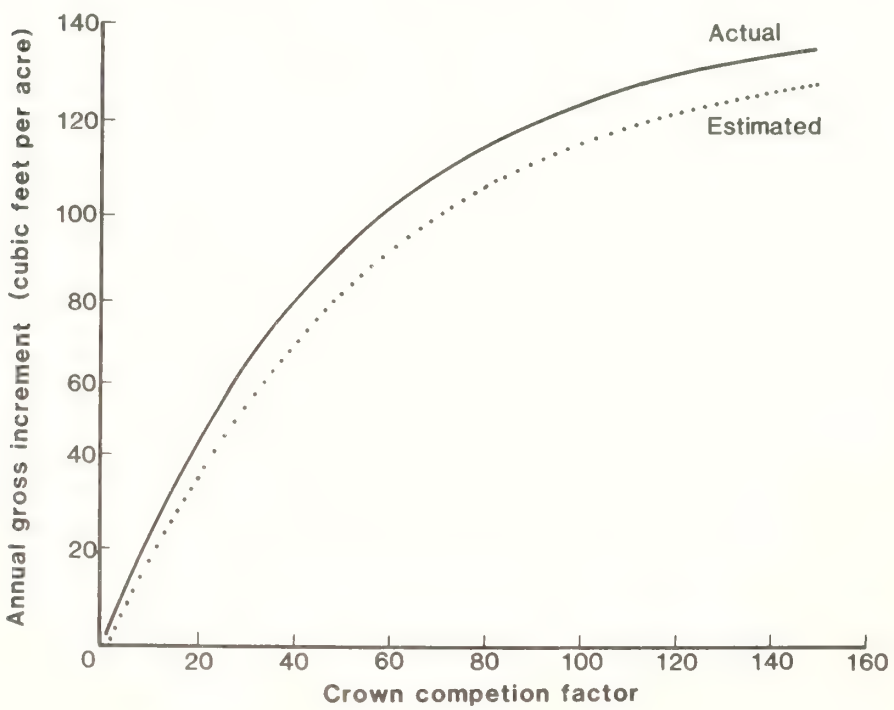
Period	Plot 11 16 × 16 feet	Plot 12 Thinned, 12 × 12 feet	Plot 13 Unthinned
Years	*Cubic feet*		
1935-39	59.6	71.2	83.5
1940-46[2]	58.3	67.8	64.2
1947-51	61.5	86.7	74.8
1952-56	67.5	100.8	79.0
1957-61	61.8	67.3	64.9
1962-66	43.3	49.6	40.5
1935-66	58.6	73.5	67.6

[1] Increment for the full 32-year period does not agree exactly with that shown in table 3 because the volume equation from the simulation model was used for the table 3 figures The volumes shown here were taken directly from table 4 of an earlier publication (Dahms 1971a). In the earlier instance, a different equation was used to express tree volume.

[2] This growth period was lengthened because research ceased during World War II

Table 5 — Comparison of actual and estimated diameter distribution, average diameter, and net-volume increment (all values per acre) for Pringle Falls lodgepole pine plots 11, 12, and 13 after 32 years of growth (estimates using combined mortality)

Item	Plot 11		Plot 12		Plot 13	
	Actual	Estimate	Actual	Estimate	Actual	Estimate
Diameter class, inches:			*Number of trees*			
4.5 and less	0	2	0	0	60	136
4.6-6.5	6	12	4	41	96	152
6.6-8.5	10	32	56	84	70	123
8.6-10.5	24	41	68	63	80	63
10.6-12.5	38	25	38	18	26	32
12.6-14.5	18	17	26	2	6	10
14.6-16.5	6	4	4	8	0	6
16.6 and up	2	5	2	10	0	5
Total	104	138	198	236	338	527
			Inches			
Average diameter	11.0	9.9	10.0	8.9	7.1	6.6
			Cubic feet			
Annual net-volume increment	35.8	42.8	50.6	47.1	21.3	51.4



The good correspondence between actual net increment and what was estimated, including the combined-mortality estimate, resulted from a lucky combination of underestimated gross-volume increment and underestimated mortality (table 5).

To sum up, the gross-increment equation underestimated gross increment on all of the plots, but particularly on the thinned ones. The amount of underestimate for the unthinned plot is certainly within the range of variation exhibited by the temporary plots used to develop the gross-increment equation. An extra response from thinning probably accounts for some of the difference between actual performance and estimated in the thinned plots, however.

The Twin Lakes and Snow Creek levels-of-growing-stock plots also provide a basis for testing performance of the gross-increment equation. Because only the shape of the curve of volume increment over stand density used in the simulator was derived from levels-of-growing-stock studies, comparing total actual production with that estimated by the simulation model seems reasonable.

Actual performance at Twin Lakes during the third 5-year growth period corresponds closely with that estimated by the simulator (fig. 11). Estimated increment amounted to 94.4 percent of actual. The curve for the fourth period fell almost exactly on top of the third-period curve, but because of increasing stand age the estimated increment would be slightly less. During the first two periods, volume increment similarly fell close to that predicted with a slight drop from the first period to the second.

Figure 11. — Actual versus estimated gross cubic-volume increment at Twin Lakes levels-of-growing-stock study.

ata from the Snow Creek levels-of-owing-stock study during the third 5-ear growth period showed estimated oss cubic-volume increment to be 2 percent of actual. During the first eriod, the very irregular curve of olume increment over stand density me close to touching the estimated rve at the highest point but was enerally well below the estimated rve (Dahms 1973). Data for the cond period are not yet available. I spect that thinning in this somewhat verdense 47-year-old stand produced extra response that temporarily shed actual performance above that timated by the simulation model ring the third period, just as parently happened in the Pringle lls plots. Data from this study during veral more growth periods might veal some important trends of volume crement in thinned stands.

oss cubic-volume increment at Snow eek started out very low during the st 5-year period after thinning ahms 1973). By the third period, owever, increment had surged bstantially ahead of estimated. The rge may well be a result of thinning older stand (47 years); the younger and at Twin Lakes (34 years) did not oduce such a surge. Results from nned stands such as those just scribed suggest that the levels-of-owing-stock studies are well worth aintaining.

omparison of Gross d Net Yields

omparison of gross and net yields sts the reasonableness of the gross-eld equation. Gross yield represents a mulative total obtained by solving e gross-increment equation starting age 10, then age 11 and adding it to e age 10 result, age 12, and adding it the previous total, and so on to the sired age.

et yield represents the live volume tually standing at the time the 94 oss-yield plots were examined. No tempt was made to eliminate defect om the standing volume.

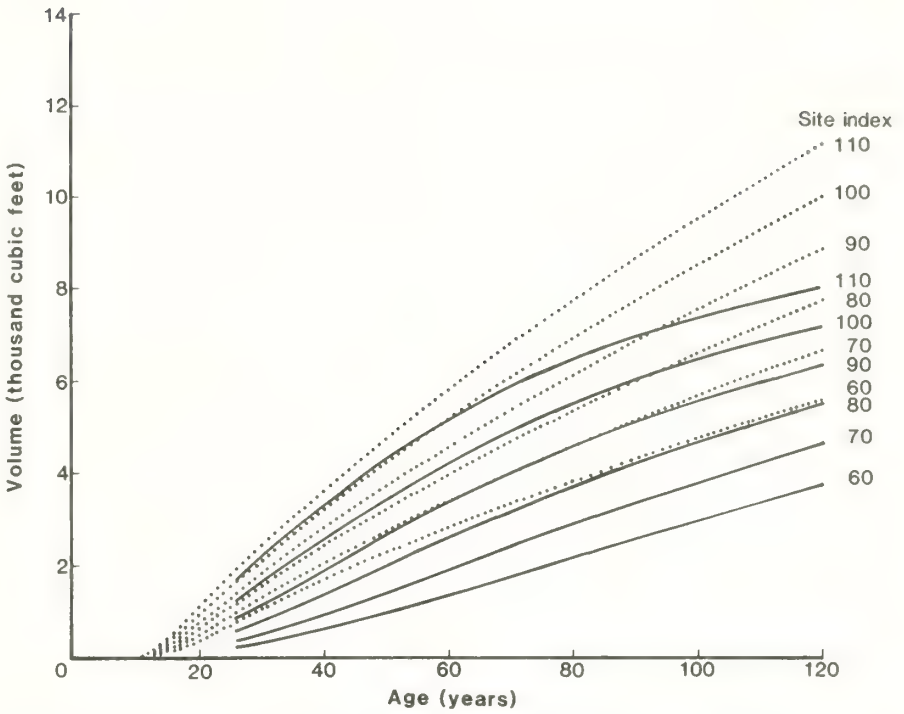


Figure 12. — A comparison of gross and net yield by age and site index at C.C.F. 175.

Net yield is expressed in equation forms as a function of age, stand density (C.C.F.), and site index. Like gross yield, it represents total cubic volume of all trees 2.6 inches in diameter and larger, including tips and stumps.

Figure 12 shows that gross yield always exceeds net; that is as it should be, because stands as old as 25 or 30 years almost certainly will have suffered some mortality or they will have been understocked during an earlier part of their lives or, usually, a little of each. At age 120 years, net yield represents from 67.3 percent of gross at site index 60 to 71.8 percent at site index 110 with a fairly steady progression of increasing percentage with increasing site index.

A comparison of gross- and net-yield ratios for other species helps put these for lodgepole pine into perspective. For ponderosa pine, Meyer (1938) reported mortality and net yields such that net yield constituted 69, 74, and 76 percent of gross at site indices 60, 80, and 100 at age 120 years. Similarly, for Douglas-fir, Staebler (1955) reported net yields represented from 71 to 75 percent of gross yield at age 120 years. The percentages for lodgepole pine thus look reasonable.

Table 6 — Actual and estimated diameter distribution, average diameter, and net cubic volume per acre on 4 lodgepole pine gross-yield plots

Item	Plot 66, site index 73		Plot 51, site index 100		Plot 68, site index 93		Plot 57, site index 83	
	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate
Diameter class, inches:				*Number of trees*				
4.5 and less	10	3	25	4	75	8	0	4
4.6-6.5	0	5	5	7	20	39	0	5
6.6-8.5	10	21	15	35	15	59	25	23
8.6-10.5	25	34	10	36	40	84	45	41
10.6-12.5	60	44	75	46	65	68	75	49
12.6-14.5	30	38	45	44	80	48	35	56
14.6-16.5	25	22	25	27	10	8	25	24
16.6 and up	10	11	5	7	20	4	5	20
Total	170	178	205	206	325	318	210	222
				Inches				
Average diameter	11.9	11.8	11.0	11.3	9.7	9.9	11.6	11.9
				Cubic feet				
Net volume	4,317	4,075	5.685	5,722	7,522	6,247	5,393	5,592

Actual Versus Estimated Diameter-Class Distributions

Estimated diameter distribution has matched actual distribution quite well over a long simulation period (table 6). Plots 51 and 68 had more very small trees than were estimated. Plot 57, however, had no very small trees, although the simulation model estimated some. A comparison of average diameter and net volume also showed close correspondence.

The actual figures were obtained from the existing stand on some of the older gross-yield plots. The youngest stand, sampled by plot 51, was 100 years old and the oldest, sampled by plot 68, was 122 years old.

We have no way of knowing what these stands looked like at age 20 or 25 years. The estimated figures were obtained by simulating growth of a 19-year-old stand at the site index of the older plot. Age of the young stand was adjusted to match actual height and the imposed site index. Plots in the young stand with spacings of 6, 9, 12, 15, and 18 feet were available (see footnote 3). A plot with a spacing was chosen that would end up with a number of trees similar to the older plot where trees had been measured.

A better comparison could be made if the number and size of trees at the beginning were known. To get the kind of correspondence achieved here, the gross-increment equation had to provide good estimates, the height-growth mechanism had to work well, and increment allocation to individual trees had to be close to what actually occurred.

Dahms, Walter G. A growth simulation model for lodgepole pine in central Oregon. Res. Pap. PNW-302. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 22 p.

A growth-simulation model for central Oregon lodgepole pine *(Pinus contorta* Dougl.) has been constructed by combining data from temporary and permanent sample plots. The model is similar to a conventional yield table with the added capacity for dealing with the stand-density variable. The simulator runs on a desk-top computer.

Keywords: Lodgepole pine (*Pinus contorta* Dougl.), yield table, variable stand density, growth simulation, gross increment, mortality, net increment, central Oregon.

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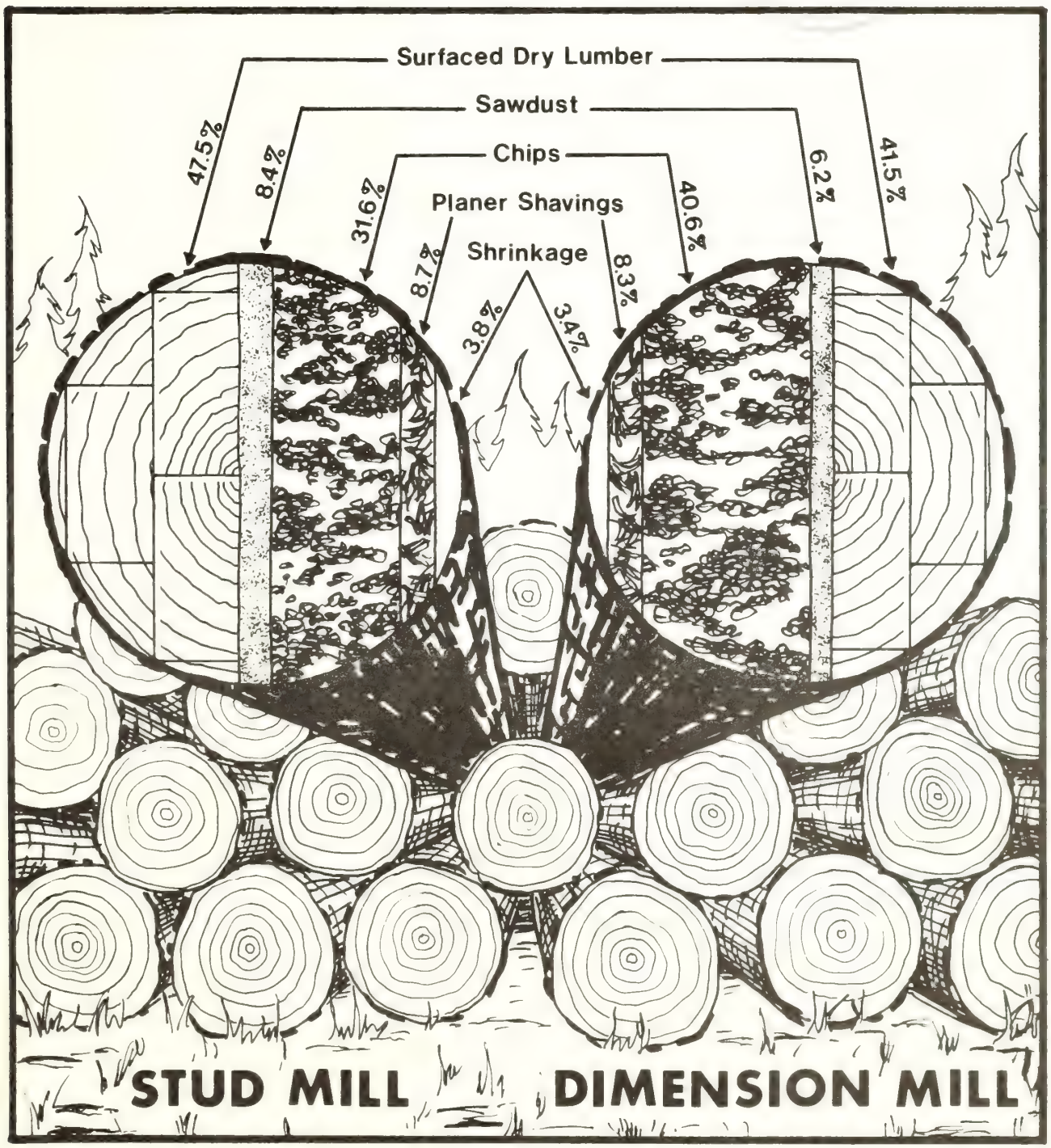
Product Recovery From Hemlock "Pulpwood" From Alaska

Thomas D. Fahey



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Abstract

Fahey, Thomas D. Product recovery from hemlock "pulpwood" from Alaska. Res. Pap. PNW-303. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 21 p.

A total of 363 western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) logs from Alaska were sawn to compare recovery at a stud mill and at a dimension mill. Recovery at both mills varied by log diameters and by log scaling system. Lumber grade recovery was primarily in Stud grade at the stud mill and in Standard and Construction grade at the dimension mill. Lumber volume recovery is based on long log Scribner scale and on cubic scale. Lumber recovery was 2.23 times the Scribner volume at the stud mill and 2.05 times the Scribner volume at the dimension mill. The lumber recovery factor was 9.0 at the stud mill and 7.5 at the dimension mill.

Keywords: Lumber yield, lumber recovery, lumber volume, log scaling, western hemlock, *Tsuga heterophylla*, pulpwood logs, dimension lumber, Alaska.

Summary

A group of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) logs from Alaska cut as pulp logs were sawn into light framing lumber, 207 at a stud mill and 156 at a mill cutting random length dimension in the Pacific Northwest. Recovery at both mills varied by log diameters and by log scaling system. Recovery was different at the two mills mainly because of lumber grading and the differences in what the mills chose to chip or save as short or narrow lumber.

Lumber grade recovery was 95 percent Utility grade or better at the stud mill and 92 percent Utility or better at the dimension mill. Most volume was in the Stud grade at the stud mill and in Standard and Construction grade at the dimension mill.

Lumber volume recovery is based on long log Scribner scale and on cubic scale. Lumber recovery was 2.23 times the Scribner volume at the stud mill and 2.05 times the Scribner volume at the dimension mill. Lumber recovery factors were 9.0 at the stud mill and 7.5 at the dimension mill.

Average cubic volumes recovered per cubic foot of log volume were:

	Stud mill	Dimension mill
Surfaced-dry lumber	47.5	41.5
Shrinkage and shavings	12.5	11.7
Rough-green lumber	60.0	53.2
Sawdust	8.4	6.2
Chips	31.6	40.6

A method of predicting volume and value of both lumber and byproducts is presented that is suitable for use in stand evaluation, product allocation, and economic analysis.

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Introduction

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) in southeast Alaska is not manufactured into the same products as in Oregon or in Washington or British Columbia. In Canada and the continental States, hemlock is used primarily for dimension lumber, but substantial volumes of both clears and "baby squares" are exported from mills on the coast. Pulp chips are the primary byproduct. In Alaska, logs larger than 15 inches scaling diameter are generally cut into export cants (Woodfin and Snellgrove 1976). Smaller logs are usually chipped for pulp. This condition is changing; currently, two new mills in Alaska are suitable for sawing small diameter logs.

The primary objective of this paper is to estimate the volume and value of light framing lumber and chips from small diameter hemlock logs from Alaska. A secondary objective is to compare volume and value of all products from a stud mill and a dimension mill. Precision end-trimmed (PET) studs and random length dimension are possible products for hemlock logs from Alaska.

Methods

Sample Selection

Logs were shipped from Prince of Wales Island in Alaska to the cooperating mills, where they were unloaded and rolled out for scaling. Logs for the study were selected on the basis of small end diameter. The sample had roughly equal numbers of logs in each diameter class from 5 through 14 inches. Logs were shipped from several logging camps and are considered representative of the range of "pulp" logs in Alaska. Sample size was 207 at the stud mill and 156 at the dimension mill. No log grade information was taken because all logs less than 12 inches in diameter would have been grade 3 because of diameter limits in the grading system. Based on surface characteristics, most of the logs would meet the grade 2 requirements.

Log Scaling

Scribner and cubic volumes of study logs were scaled by USDA Forest Service and industry check scalers. Long log Scribner scale was taken, using the Alaska interpretation of the Puget Sound Scaling Bureau Rules.[1/] The Alaska rules vary on two points: (1) a 42-foot log is scaled as one piece instead of as two pieces, and (2) on split-scaled logs, a midpoint measurement is used rather than the standard taper allowance of 1 inch in 10 feet.

Cubic scale was taken in conformance with the cubic log scaling handbook.[2/] Scale at the stud mill was compared among scalers, then reconciled by jointly remeasuring any logs about which the scalers disagreed. Scale at the dimension mill was not reconciled but was cross-checked against other scaling records and is considered accurate. The two scaling systems are different in both concept and application and are roughly defined as follows:

1/ Official Log Scaling and Grading Rules. Puget Sound Log Scaling and Grading Bureau, Tacoma, Washington; January 1978.

2/ Cubic Scaling Handbook (review draft), National Cubic Measurement Committee, USDA Forest Service, Washington, D.C.; August 1978.

Scribner scale is the theoretical board-foot volume in 1-inch boards that can be recovered from a cylinder equal to the small end diameter of the log. Fractional inches are dropped, and deductions are made for defects thought to reduce the volume of merchantable lumber that can be produced from the log.

Cubic product scale (cubic scale) estimates the volume of fiber in the log from the diameter of both ends and log length. Fractional inches are rounded, and deductions are made for defects expected to reduce the volume of merchantable lumber.

Study Mills

Both mills used for the study were modern, efficient, well-run plants. Quality control and mill target sizes were in accord with the grading rules for the product line being produced. Both mills used continuous rising temperature (CRT) kiln schedules of about 72 hours.

Lumber was planed, then graded by certified company graders under the supervision of a West Coast Lumber Inspection Bureau (WCLIB) quality supervisor. All lumber was graded surfaced dry except: at the stud mill 2x2's and 1x4's were graded rough green; at the dimension mill 1x4's, 1x6's, and 2x3's were graded surfaced green. All lumber was tallied as shipped by the mill. Data were compiled by both surfaced-dry and actual rough-green lumber dimensions to provide an accounting of all cubic volume.

At both mills, logs were bucked to mill lengths and sawn to produce the mills' normal product line. Logs and boards were identified so that every board could be identified with the log from which it was cut. The dimension mill saved 1x4's, 1x6's, 2x3's, 2x4's, and 2x6's 6 feet and longer in even lengths only. At the stud mill items saved were 1x4's, 2x2's, 2x3's, 2x4's, and 2x6's, primarily PET 92-5/8 inches long; 6-foot-long 2x6's were also saved, as well as 2x4's in 4- and 5-foot lengths (finger-joint stock) and 6- and 7-foot and 88-5/8-inch PET Stud grade.

Product Prices

An index pricing system, which avoids the effect of market fluctuation and makes repricing easier, was used. A base price of $200 per thousand board feet (MBF) was picked for random length 2x4 and 2x6 of Standard or No. 2 and better grade. Prices for Stud, Utility, and Economy grades were developed using the average ratio of their prices to 4-inch-wide Standard and Better prices for the years 1976 to 1980 as supplied by Western Wood Products Association. The average ratio for this period was 93.5 percent for studs, so the indexed price per thousand board feet for studs is $200 x 0.935 or $187. Other prices were developed by the same general technique.

Prices used for the two mills were:

Dimension mill	$/MBF	Stud mill	$/MBF
Standard No. 2 and Better	200	PET Stud	187
1650f	200	1650f	187
Selects	325	Selects	325
Utility No. 3	126	Utility Stud	126
Economy	65	Economy Stud	65
2x3 Utility and Better	175	2x4 (4 to 7 ft) Stud	130
1-inch board Standard	175	1x4 mill run	76
1-inch board Utility	126	2x3 PET Stud	175
1-inch board Economy	65	2x2 mill run	116

nalysis of Data

The objectives of analysis were to: (1) determine suitable models for estimating product volume and value recovery and (2) compare recovery between the stud mill and the dimension mill. Linear and curvilinear models were used where appropriate.

Product recovery information has typically been assumed to vary with log diameter (Woodfin and Snellgrove 1976), but estimating recovery from log scale is easier and more direct (Fahey and others 1981). Both methods were used in this paper.

Research has shown that for most recovery by log diameter, a polynomial equation using the general term scaling diameter (D) and transformations D^2, $1/D$, and $1/D^2$—singly or in combination—best describes the relationship. Coefficient of determination (R^2) and F value were criteria for selecting the model. Where curvilinear models are displayed, regressions were run for D, $D+D^2$, $D+1/D$, $D+1/D^2$, and $D+1/D+1/D^2$, and the best fit was selected.

Lumber volume, lumber value, and chip volume were all assumed to have a linear relationship to log volume, so a linear model was used to compare mills.

Where results from the two mills are compared, analysis of covariance was used. Results were considered significantly different if the probability of the results occurring by chance were 0.05 or less ($p<0.05$). Results of analysis are discussed in the appropriate results section.

esults and iscussion

The results are presented in tables and figures. Recovery value is index priced so that it can be updated (see "Product Prices"). Results based on Scaling Bureau Scribner scale are applicable only in Alaska where this scaling system is used. Lumber grade recovery and the cubic volume information are applicable throughout the range of western hemlock.

umber Grade Recovery

The lumber grade recovery was typical of small diameter hemlock and fir (hem-fir) at west coast mills (Fahey and Hunt 1975), a very small volume of selects with most of it meeting the requirements of the dimension lumber grades.

In table 1 the 1650f visually stress-rated lumber is reported separately for information but is priced with Standard and Better or Studs (see "Product Prices") for the value section of this paper. Short studs 6 and 7 feet long are priced differently than PET studs. Finger-joint is 4- and 5-foot-long Stud grade lumber.

The biggest difference in lumber grade between the mills is in the percent of Utility grade lumber—4 percent at the stud mill and 28 percent at the dimension mill. This is related to both the lumber grading rules and board length. Stud grade allows a larger knot size than does Standard grade; a long board has a higher probability of having a grade-limiting knot than does an 8-foot stud. Some of the Stud grade lumber would have been Utility grade under the dimension grade rules if graded as 8-foot 2x4's.

The stud mill salvaged some items that were not saved at the dimension mill. Both 2x2's and short pieces less than 6 feet long were salvaged at the stud mill. This will affect the percentage of cubic volume recovered as lumber, sawdust, and chips and also the recovery percent.

Table 1—Total lumber production of hemlock logs from Alaska, by grade and size, for a stud mill and a dimension mill

Mill and lumber size	Selects	1650f	Stud[1/]	Finger-joint	Construction No. 1	Standard No. 2	Utility and Better	Utility No. 3	Economy	Total
Inches	Percent									
Stud mill:										
1x4							2.25			2.25
2x2							3.27			3.27
2x3			5.44							5.44
2x4	2.09	13.76	57.39	3.28				4.36	5.06	85.94
2x6	.01		2.94	.04				.01	.10	3.10
Total	2.10	13.76	65.77	3.32			5.52	4.37	5.16	100.00
Dimension mill:										
1x4							2.28			2.28
1x6							2.24			2.24
2x3	.06	.02			0.39	0.35		.75	.39	1.96
2x4	1.29	4.21			12.90	23.10		20.32	5.72	67.54
2x6	.33	1.34			4.36	11.36		6.74	1.87	25.98
Total	1.67	5.57			17.65	34.81	4.52	27.79	7.98	100.00

[1/]All 2x3's 92-5/8-inch PET Stud; 2x4's include 4.52 percent 6-foot Stud, 6.56 percent 7-foot Stud, 39.26 percent 92-5/8-inch PET Stud, and 7.13 percent 88-5/8-inch PET Stud; 2x6's include 0.67 percent 6-foot Stud and 2.27 percent 92-5/8-inch Stud.

Regression analysis was used to test for a linear correlation between lumber grade and log size at both mills. At the stud mill, the dependent variable was Stud grade plus 1650f as a percent of total lumber. There was no correlation between the lumber grade and log scaling diameter. The same test was run at the dimension mill using the Standard No. 2 and Better grade group as the dependent variable. Again, there was no correlation between log diameter and lumber grade. Lumber grade was not related to log diameter at either mill, so average lumber grade recovery can be used.

Recovery Percent Scribner Scale (Overrun)

Overrun is the recovery in lumber tally over and above net log scale expressed as a percentage of log scale:

$$\text{Overrun} = \frac{\text{Lumber tally - log scale}}{\text{Log scale}} \times 100.$$

Recovery percent is lumber tally divided by log scale:

$$\text{Recovery percent} = \frac{\text{Lumber tally}}{\text{Log scale}} \times 100.$$

A recovery percent of 200 would be equal to 100 percent overrun. Recovery percent is used throughout this report.

There is an apparent difference in average recovery between the two mills, 223 percent at the stud mill and 205 percent at the dimension mill. There is also considerable variation in recovery by diameter class for each mill (table 2). There is also a difference in "average" log volume between mills. Recovery varies by log diameter, so to test if the difference between the two mills is significant, recovery percent was plotted over diameter (fig. 1) and an analysis of covariance was used.

When recovery for the two mills was compared on the same diameter basis, recovery percent at the stud mill was 24 percent higher than at the dimension mill. This difference was not significant ($p<0.05$) for either slope or intercept because of the high variation around the recovery curves. The difference in intercept ($p<0.10$) was important enough that separate curves with the same slope are shown.

A 24-percent difference in recovery percent—although of practical importance—was not statistically detectable because the variation was so great, but both mills recovered more than double the scaled volume. Together, these facts indicate little relationship between the measurement system and what it is supposed to measure.

Lumber Recovery Factor

The lumber recovery factor (LRF)—board feet of lumber tally divided by cubic feet of log scale—varied between mills—9.0 at the stud mill and 7.5 at the dimension mill. It also varied with log diameter; individual factors for each mill and for each diameter class are in table 3, and the curved recovery by small-end diameter is in figure 2. Analysis of covariance showed that slope of the two lines was not significantly different, but the difference in intercept was significant at the 0.01-probability level. There was much less variation around the LRF lines than around the percent recovery based on Scribner scale.

Table 2—Recovery percent (overrun) of hemlock logs from Alaska, by long log Scribner scale

Scaling diameter	Stud mill						Dimension mill					
	No. of logs	Log scale		Percent sound	Lumber tally	Recovery	No. of logs	Log scale		Percent sound	Lumber tally	Recovery
		Gross	Net					Gross	Net			
Inches		Board feet			Board feet	Percent		Board feet			Board feet	Percent
4	4	100	100	100	499	499	--	--	--	--	--	--
5	20	510	470	92	1,348	287	9	260	260	100	604	232
6	24	1,010	890	88	2,664	299	20	970	920	95	2,033	221
7	14	780	750	96	1,786	238	17	800	720	90	17,886	248
8	25	1,760	1,610	91	4,669	290	25	1,940	1,810	93	3,953	218
9	18	1,400	1,280	91	3,336	261	16	1,130	970	86	2,108	217
10	15	2,720	2,470	91	5,387	218	15	1,590	1,770	90	3,390	213
11	21	3,440	3,230	94	7,080	219	15	1,750	1,600	91	3,467	217
12	25	5,220	4,620	89	9,987	216	17	2,850	2,530	89	4,995	197
13	17	4,150	3,980	96	7,967	200	12	2,620	2,260	86	4,576	207
14	21	5,760	5,440	94	10,888	200	8	1,960	1,760	90	2,753	156
15+	3	810	760	94	1,366	180	2	270	230	85	391	170
Total or average	207	27,660	25,600	93	56,977	223	156	16,320	14,650	90	30,056	205

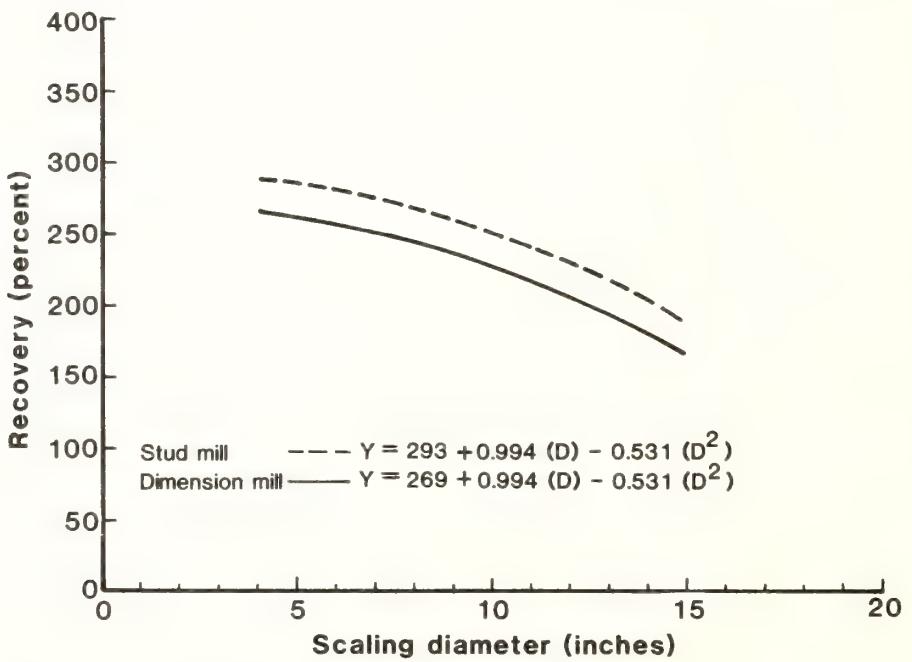

Figure 1.—Lumber recovery as a percent of net Scribner scale, by log scaling diameter.

Table 3—Cubic volume of products from hemlock logs from Alaska

Mill and diameter	Number of logs	Gross volume	Product volume	Lumber tally	Lumber recovery factor	Rough-green lumber	Surfaced-dry lumber	Sawdust	Chippable volume
Inches		- Cubic feet -		Board feet		- - - - - - Cubic feet - - - - - - -			
Stud mill:									
5	13	139.0	137.0	1,184	8.6	79.0	62.6	11.1	46.9
6	24	273.6	254.3	1,880	7.4	125.4	99.0	17.8	111.1
7	17	298.2	291.4	2,305	7.9	152.3	121.2	21.7	117.0
8	18	377.3	314.0	2,977	9.5	198.2	157.3	27.8	88.0
9	22	572.7	560.6	3,742	6.7	248.8	197.2	34.8	277.0
10	16	487.7	468.7	4,316	9.2	288.4	228.0	40.3	140.0
11	21	718.1	683.9	6,529	9.5	432.5	343.0	60.9	190.5
12	24	1,045.7	1,006.2	9,451	9.4	629.3	498.0	87.9	289.1
13	18	861.4	807.5	7,293	9.0	484.7	384.0	67.9	254.9
14	25	1,371.2	1,343.8	13,259	9.9	879.7	697.7	122.8	341.3
15	9	455.0	446.2	4,041	9.1	270.0	212.3	37.6	138.6
Total or average	207	6,559.9	6,313.6	56,977	9.0	3,788.7	3,000.3	530.5	1,994.4
Dimension mill:									
5	2	30.7	30.5	233	7.6	16.4	12.8	1.9	12.2
6	20	240.0	224.8	1,563	7.0	110.6	85.9	13.1	101.1
7	16	248.6	243.1	1,540	6.3	109.2	85.1	12.9	120.9
8	23	504.2	490.2	3,345	6.8	236.9	185.0	27.6	225.6
9	17	395.3	381.6	2,863	7.5	203.1	158.6	24.0	154.5
10	20	414.6	373.7	2,805	7.5	199.2	155.8	23.3	151.2
11	14	368.2	352.7	2,834	8.0	200.8	156.7	23.7	128.3
12	14	588.3	563.0	4,333	7.7	307.5	240.4	35.9	219.6
13	13	595.5	582.7	4,716	8.1	334.7	261.6	38.7	209.3
14	13	699.3	651.9	5,118	7.9	362.9	282.6	42.6	246.4
15+	4	138.7	113.8	706	6.2	501.	39.0	6.0	57.7
Total or average	156	4,223.4	4,008.0	30,056	7.5	2,131.4	1,664.5	249.7	1,626.9

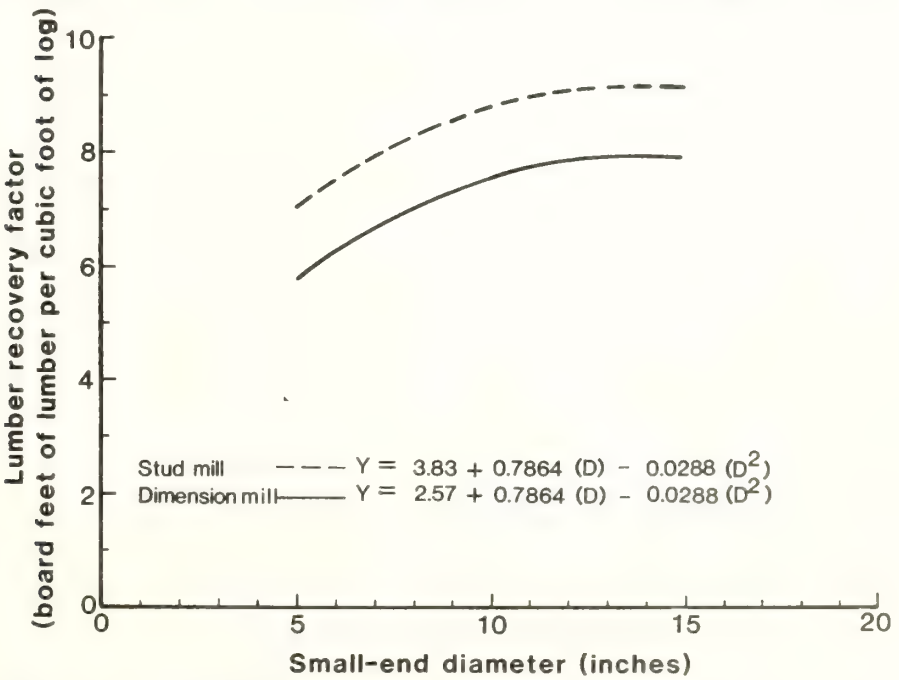

Figure 2.—Lumber recovery factor by small-end diameter.

Table 4—Cubic volume of lumber from hemlock logs from Alaska as a percent of cubic scale

Mill and diameter	Number of logs	Rough-green lumber	Surfaced-dry lumber	Shrinkage and shavings	Sawdust	Chippable volume
Inches		- - - - - - - - - - - - - Percent - - - - - - - - - - - - -				
Stud mill:						
5	13	58	46	12	8	34
6	24	49	39	10	7	44
7	17	52	42	10	7	41
8	18	63	50	13	9	28
9	22	44	35	9	6	50
10	16	62	49	13	9	29
11	21	63	50	13	9	28
12	24	63	49	14	9	28
13	18	60	48	12	8	32
14	25	65	52	13	9	26
15	9	65	52	13	9	26
Total or average	207	60.0	47.5	12.5	8.4	31.6
Dimension mill:						
5	2	54	42	12	6	40
6	20	49	38	11	6	45
7	16	45	35	10	5	50
8	23	48	38	10	6	46
9	17	53	42	11	6	40
10	20	53	42	11	6	40
11	14	57	44	13	7	36
12	14	55	43	12	6	39
13	13	57	45	12	7	36
14	13	56	43	13	7	38
15+	4	38	29	9	5	58
Total or average	156	53.2	41.5	11.7	6.2	40.6

Cubic Volume of Logs and Products

Cubic volumes give the best estimates of recovery of all products. How much of the log was converted to rough-green lumber and ultimately to finished lumber? How much sawdust was generated and what volume of chips was sold?

The volume by component is in table 3, the percent of recovery by component by diameter class in table 4, and curved recovery by log diameter in figure 3. Covariance analysis was used to compare recovery of rough-green, surfaced-dry, and chippable volumes between the two mills. In all cases, analysis indicated that the slope of the curves was not different, but the intercepts were significantly different at the 1-percent level of probability.

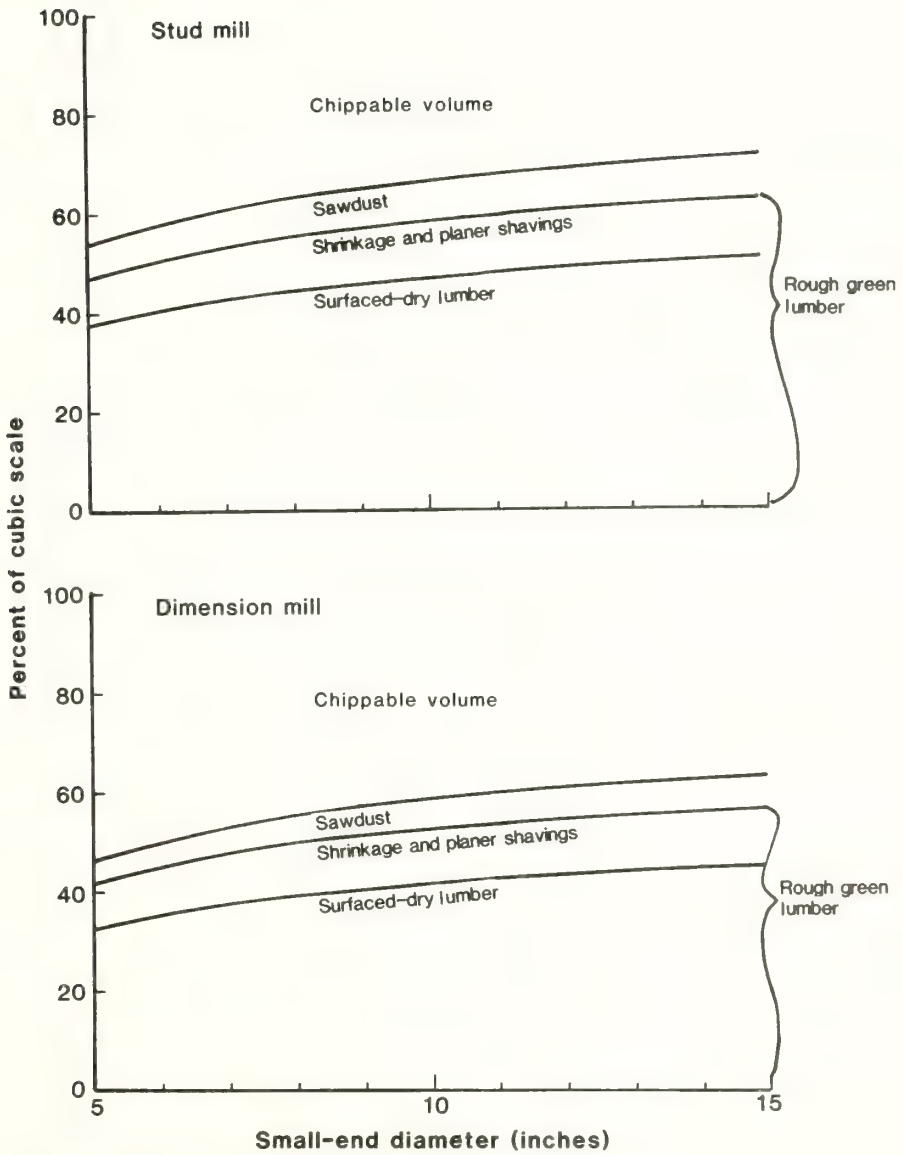

Figure 3.—Cumulative recovery and loss as a percent of cubic scale, by small-end diameter, for a stud mill and a dimension mill.
Stud mill: Rough green lumber and sawdust—Y = 72.7 + 0.213(D) - 116.5/D;
rough green lumber—Y = 66.6 + 0.185(D) - 103.9/D;
surfaced-dry lumber—Y = 53.4 + 0.117(D) - 85.0/D.
Dimension mill: Rough green lumber and sawdust—Y = 68.6 + 0.213(D) - 116.5/D;
rough green lumber—Y = 61.4 + 0.185(D) - 103.9/D;
surfaced-dry lumber—Y = 48.6 + 0.117(D) - 85.0/D.

The general averages in table 4 plus the lumber grade and items from table 1 are needed to explain the differences in volume between the two mills. The stud mill recovered 6.8 percent more of the log volume in rough-green lumber than did the dimension mill. Most of that gain was due to saving material that was not salvaged at the dimension mill. Recovery of 2x2's and finger-joint material accounts for 4 percent of the difference. Saving 7-foot and PET 88-5/8-inch studs from boards that would have been cut back to 6 feet at the dimension mill accounts for 1.6 percent. A very small portion, 0.2 percent, was due to difference in log diameter. The reason for the remaining 1 percent is unknown but is probably due to the sawyer's ability to select an efficient sawing pattern for each 8-foot segment rather than having to select a pattern for a longer log.

The stud mill used more of the log for planer shavings and shrinkage for two reasons: (1) it produced more lumber so it had to dry and plane more, and (2) it had more of the lumber in smaller items which have more surface to plane for every board foot produced. The actual allowance for planing was less at the stud mill because studs are allowed more planer skip than is allowed in Standard and Better dimension grades, and target sizes for rough-green lumber at each mill were set accordingly.

Sawdust volume was lower at the dimension mill because of less lumber produced, lower surface area per board foot, and a 0.140 saw kerf compared with a 0.160 kerf at the stud mill.

Less rough-green lumber and less sawdust resulted in more chippable volume at the dimension mill than at the stud mill. Both local markets and production costs for the individual mills need to be considered by each mill to determine whether to chip or saw the salvage items.

The cubic volumes recovered can be used to measure relative efficiency of the two mills. Both mills processing the study logs were efficient. Some differences in items saved exaggerate the slight advantage in efficiency that stud mills have over dimension mills. Saving 4- and 5-foot Stud grade and 2x2's plus the stud mill's ability to save 88-5/8-inch PET Stud and 7-foot Stud from material that would have been cut back to 6 feet at a dimension mill account for most of the difference in cubic volume of rough-green lumber recovered.

Besides the cubic volume of rough-green lumber, the other factor in determining LRF is board feet per cubic foot of lumber (Fahey and Woodfin 1976). Because the planer skip allowance for studs is greater than for Standard grade dimension, stud mills allow less for sawing variation and planing than do dimension mills. The approximate thickness of rough-green, 2-inch studs at the stud mill was 1.70 inches, whereas the thickness at the dimension mill was 1.74 inches. Board feet per cubic foot of lumber were 15.04 for the stud mill and 14.10 for the dimension mill.

Most of the differences between these two mills can be explained in terms of what lumber sizes mill management chose to save, and that studs can be cut smaller than dimension and still meet grading specifications.

Log Values

Log value is generally expressed in units of log measurement. Lumber grade and market price determine lumber value. This value is multiplied by the appropriate recovery percent or factor, and the result is either dollars per thousand board feet net Scribner log scale ($/MNLS) or dollars per hundred cubic feet product scale ($/CCF). These estimates have a total variation that cannot be quantified exactly because they combine several sources of variation. Biological variation in wood quality caused by either growth patterns or decay can affect both volume and value of wood recovered. Mechanical damage at the barker or mismanufacture in the sawmill or planer can have a negative effect on either volume or quality of lumber or both. Finally, the scaling system can introduce a great deal of variation. Both the method of computing gross volume and the method of deducting for defects affect variation. Both samples in this study were carefully scaled and manufactured with minimal breakage or mismanufacture so the error terms should be primarily biological variation and effect of scaling system. There was no correlation between lumber grade and diameter; therefore, variation in value should be primarily due to differences in lumber volume as a function of log volume.

Both $/MNLS (table 5) and $/CCF (table 6) are expected to vary with log diameter, and they did (figs. 4 and 5). Covariance analysis of $/MNLS showed that neither the slopes nor the intercepts were significantly different between the two mills. There was a $34 difference in source means that was not statistically significant because of the wide variation (fig. 4). Because of the size of the difference in intercepts, it is shown as two separate lines ($p<0.20$) despite the lack of statistical significance.

The $/CCF also varied by log diameter, scaling system being the only difference (fig. 5). Covariance analysis showed that the slope of the lines was not significantly different but that the intercepts were different at the 1-percent probability level. There was a difference of about $18/CCF between the lumber values at the two mills. This difference did not vary by log diameter.

Because these are the same logs with the same total values (only log scale differed), one method of estimating the value of lumber recovered from logs is more reliable than the other. To demonstrate which measurement system had the lower variation, the standard deviation (Sx) around the sample mean and the standard error of estimate (Sy·x) around the regression line were calculated as a percent of mean value using separate means and parallel regression lines:

Value	Scaling system	$Sx/\bar{x}$	$Sy{\cdot}x/\bar{x}$
$/MNLS	Net Scribner scale	54.5	53.6
$/CCF	Cubic scale	31.6	30.2

Cubic scale was, as expected, a better predictor of log value than was Scribner scale. This result conforms to results with white pine (Snellgrove and Cahill 1980).

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Table 5—Average value of lumber from hemlock logs from Alaska, by long log Scribner scale

Mill and diameter	Number of logs	Scribner scale		Defect	Total value	Product
		Gross	Net			
Inches		- Board feet - -		Percent	Dollars	$/MNLS[1/]
Stud mill:						
4	4	100	100	0	79.88	799
5	20	510	470	8	212.89	453
6	24	1,101	8790	12	422.19	474
7	14	780	750	4	287.64	384
8	25	1,760	1,610	9	782.84	486
9	18	1,400	1,280	9	562.14	439
10	15	2,720	2,470	9	905.16	366
11	21	3,440	3,230	6	1,203.96	373
12	25	5,220	4,620	11	1,653.73	358
13	17	4,150	3,980	4	1,358.47	341
14	21	5,760	5,440	6	1,817.17	334
15	3	810	760	6	220.49	290
Total or average	207	37,660	25,600	7	9,506.56	371
Dimension mill:						
5	9	260	260	0	101.53	391
6	20	970	920	5	349.97	380
7	17	800	720	10	340.73	423
8	25	1,940	1,810	7	641.08	354
9	16	1,130	970	14	343.55	354
10	15	1,770	1,590	10	542.60	341
11	15	1,750	1,600	9	611.72	382
12	17	2,850	2,530	11	854.44	338
13	12	2,620	2,260	14	793.08	351
14	8	1,960	1,760	10	443.25	252
15+	2	270	230	15	73.95	322
Total or average	156	16,349	14,670	10	5,059.90	345

[1/]Dollars per thousand board feet, net Scribner log scale.

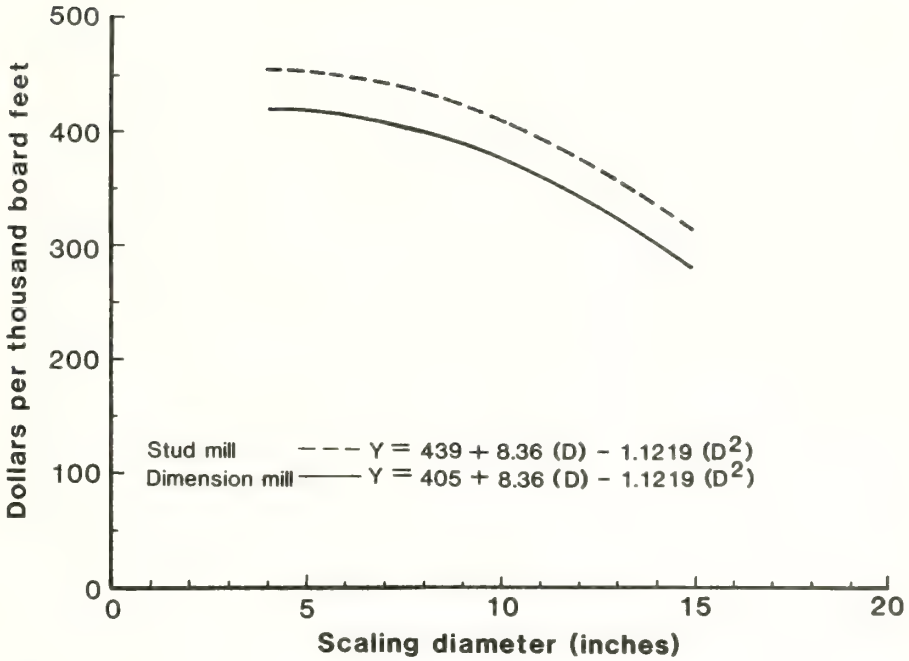

Figure 4.—Dollars per thousand board feet of logs, net Scribner scale, by scaling diameter.

Table 6—Average value of lumber from hemlock logs from Alaska, by cubic scale

Mill and diameter	Number of logs	Cubic scale		Defect	Total value	Product
		Gross	Net			
Inches		- Cubic feet - -		Percent	Dollars	$/CCF[1/]
Stud mill:						
5	13	139.0	137.0	2	189.58	138
6	24	273.6	254.3	7	291.75	115
7	17	298.2	291.4	2	371.19	127
8	18	337.3	314.0	7	496.87	158
9	22	572.7	560.6	2	626.68	112
10	16	487.7	468.7	4	708.87	151
11	21	718.1	6783.9	5	1,125.18	165
12	24	1,045.7	1,006.2	4	1,587.44	158
13	18	861.4	807.5	6	1,199.22	149
14	25	1,371.2	1,343.8	2	2,236.95	166
15	9	455.0	446.2	2	672.83	151
Total or average	207	6,559.9	6,313.6	4	9,506.56	151
Dimension mill:						
5	2	30.7	30.5	1	41.67	247
6	20	240.0	224.8	6	269.40	120
7	16	248.6	243.1	2	256.39	105
8	23	504.2	790.2	3	547.69	112
9	17	395.3	381.6	3	469.52	123
10	20	414.6	373.7	10	461.60	124
11	14	368.2	352.7	4	461.15	131
12	14	588.3	563.0	4	743.66	132
13	13	595.5	582.7	2	825.01	142
14	13	699.3	751.9	7	862.97	132
15+	4	138.7	113.8	17	120.84	107
Total or average	156	4,223.4	4,008.0	5	5,059.90	126

[1/]Dollars per hundred cubic feet.

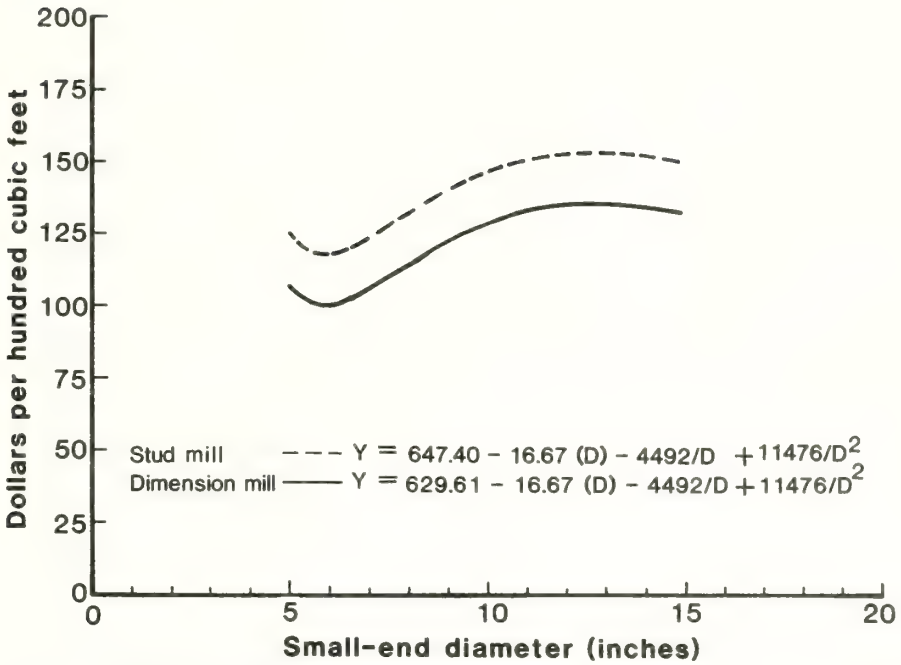

Figure 5.—Dollars per hundred cubic feet of logs, by small-end diameter.

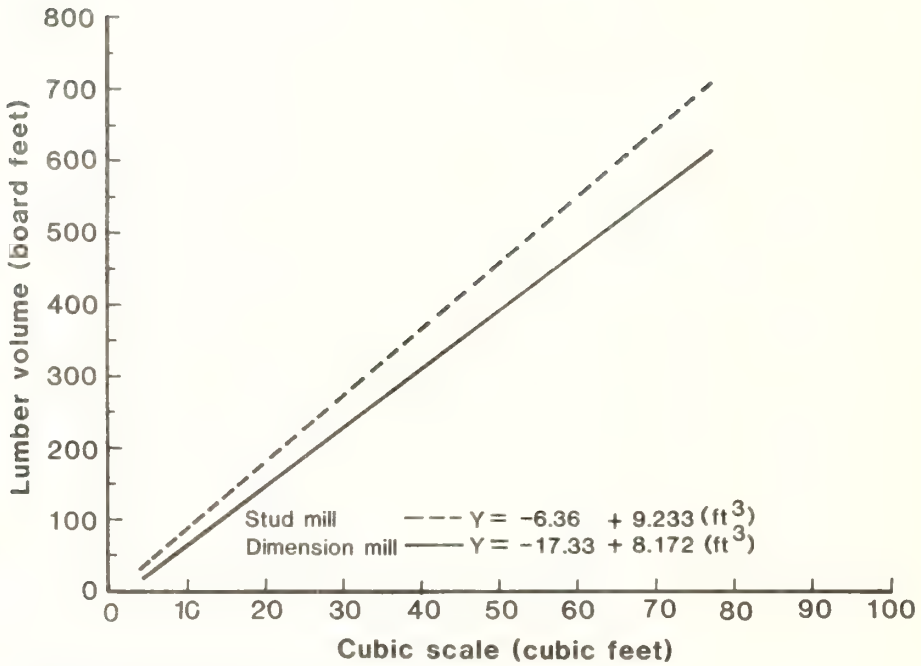

Figure 6.—Total lumber volume in board feet, by log cubic scale.

Direct Product Estimators

Product volume and value can be predicted directly from log scale (Fahey and others 1981). Cubic scale was used because it is much less variable than Scribner scale. The same type of estimate can be made for Scribner scale but at a considerable loss in precision.

Total lumber tally from a log is directly related to the cubic volume of the log. Total value of lumber and volume of chippable fiber are also correlated with log volume. The relationship between lumber tally and cubic log scale is shown in figure 6. The coefficient of determination (r^2) between cubic scale and lumber tally is 0.85 at the stud mill and 0.93 at the dimension mill. The slopes of the two lines are significantly different at the 1-percent probability level.

Lumber value is also directly correlated to cubic scale (fig. 7). Calculated r^2 is 0.82 at the stud mill and 0.89 at the dimension mill. The slopes of the two lines are different at the 1-percent probability level.

Volume of chippable wood can also be estimated from log cubic volume (fig. 8); r^2 is 0.51 at the stud mill and 0.80 at the dimension mill. Slopes are different at the 1-percent probability level. Use of these figures will be discussed in "Application."

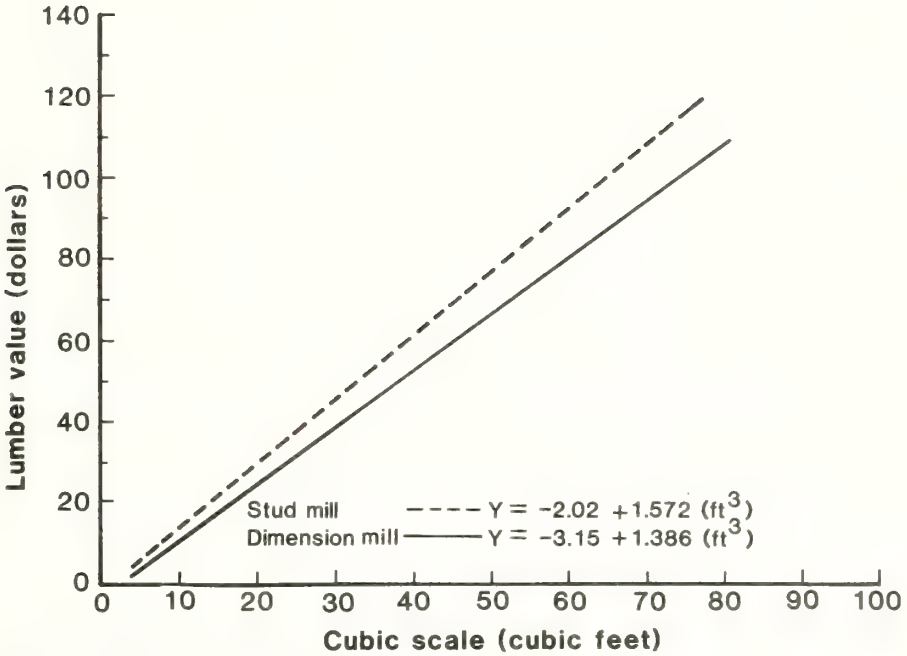

Figure 7.—Total lumber value by log cubic scale.

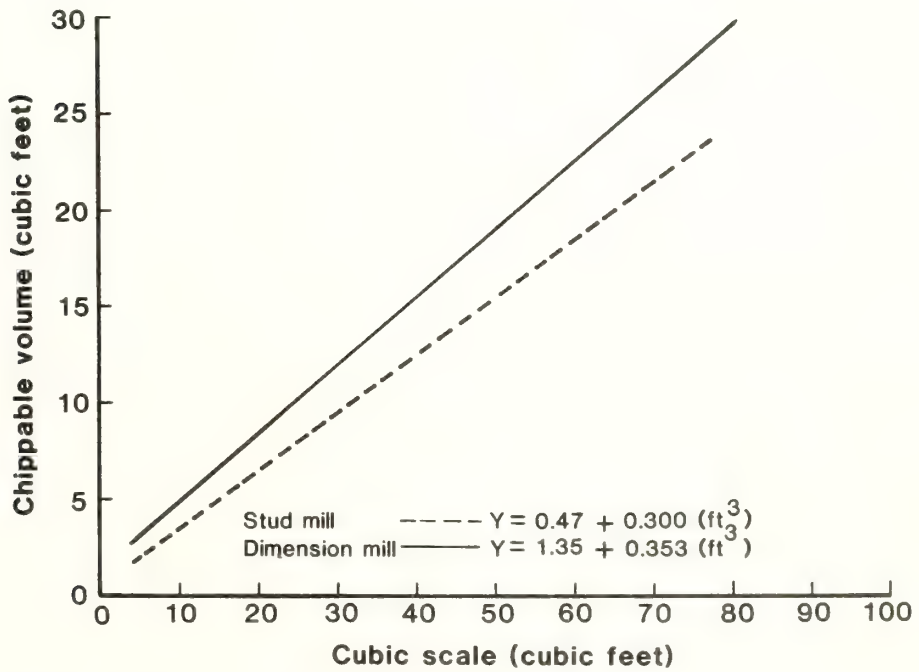

Figure 8.—Chippable volume by log cubic scale.

Application

From the information in figures 6, 7, and 8 and the stud mill as an example, the volume and value of lumber and chips can be estimated directly for any log.

For a log containing 10 cubic feet (CF), volume or value is estimated from the equations that describe the relationships in figures 6, 7, and 8. For example:

Lumber tally = -6.36 + (9.233 x 10 CF) = 86 BF (board feet).
Lumber value = -2.02 + (1.572 x 10 CF) = $13.70.
Chippable volume = 0.47 + (0.300 x 10 CF) = 3.47 CF.

If a chip price of $80 per oven-dry ton or $0.04 per pound is assumed and 24 pounds per cubic foot on an oven-dry weight per green volume basis (Wangaard 1950) is used, there are 83 pounds of chippable fiber with a value of $3.33; total value = $17.03.

At the dimension mill, the results would be a little different:

Lumber tally = -17.33 + (8.172 x 10 CF) = 64 BF.
Lumber value = -3.15 + (1.386 x 10 CF) = $11.71.
Chippable volume = 1.35 + (0.353 x 10 CF) = 4.88 CF
= 117 lb at $0.04 = $4.68; total value = $16.39.

This does not include direct manufacturing costs, which would be higher at the stud mill because of processing and saving the smaller lumber items such as 2x2's and finger-joint.

If this procedure works for one log, it will work for a group of logs. As an example, take a group of small logs where 120 logs equal 1,000 cubic feet (MCF), and a group of larger logs where 20 logs equal 1,000 cubic feet.

Total lumber at the stud mill for each group would be:

-6.36 (120) + 9.233 (1000) = 8,470 BF;
-6.36 (20) + 9.233 (1000) = 9,106 BF.

Lumber value = -2.02 (120) + 1.572 (1000) = $1,330;
-2.02 (20) + 1.572 (1000) = $1,530.

Chip volume = 0.47 (120) + 0.300 (1000) = 356 CF = $342;
0.47 (20) + 0.300 (1000) = 309 CF = $297.

From the estimates of lumber value, total value, total lumber tally, and log scale, calculate $/MLT or LRF:

Logs/MCF	Large logs (20/MCF)	Small logs (120/MCF)
(1) Total lumber tally, BF	9,106.00	8,470.00
(2) Total lumber value, dollars	1,530.00	1,330.00
(3) Total log scale, CF	1,000.00	1,000.00
(4) Total value including chips, dollars	1,827.00	1,672.00
$/MBF lumber tally (2)/(1)x1,000	168.00	157.00
$/CCF (4)/(3)x100	182.70	167.20
LRF (1)/(3)	9.106	8.470

For the larger logs, the average $/MBF increased. Although percentage by lumber grades did not vary with log size (diameter), a higher percentage of the lumber is recovered in the high value PET lengths and less in the salvage items, such as short studs and 2x2's.

Because the lumber is index priced, it is relatively easy to update prices to current levels; calculate total lumber value first, then adjust by the ratio of current price of PET Stud to the $187 price used for PET Stud.

Other adjustments are possible and only slightly more difficult. The 8-foot rough-green 1x4 is of marginal value as is indicated by its $76/MBF selling price. If the mill chose to chip this item, lumber, volume of chips, and value would all change. In table 1, about 2.3 percent of the lumber volume was in 1x4 mill run. The result of chipping this would be a 2.3-percent decline in lumber tally. Lumber value would decline about 1 percent. This can be calculated several ways. Volume and value of chips would increase by 2.3 percent x (rough-green recovery percent from table 4) x log volume.

It is now possible to rework the example for 120 logs and 1,000 cubic feet from the stud mill.

From the earlier example, volume and value are:

	Volume	Value
Lumber	8,470 BF	$1,330
Chippable volume	356 CF	$342

Adjusting lumber tally is easy:

8,470 x 97.7% = 8,275 BF.

Adjusting lumber value is slightly more complex:

Either -2.3% x 76/157 = -1.113% of value so $1,330 x 0.9887 = $1,315,
or 195 BF x $76/1,000 = $15. So $1,330 - $15 = $1,315,
and finally, 2.3% x 60% (cubic recovery percent of rough-green lumber) x 1,000 CF = 14 CF of additional cubic volume to chips.
Adjusted chip volume is 370 CF or $355.

The effect on value can be displayed as follows:

	Lumber	Lumber value	Chip volume	Chip value	Total value
	(Board feet)	(Dollars)	(Cubic feet)	(Dollars)	(Dollars)
With 1x4	8,470	1,330	356	342	1,672
Without 1x4	8,275	1,315	370	355	1,670

At these prices, there is little or no advantage to producing the low valued lumber.

Conclusions

One major conclusion can be drawn from the study; it is possible to produce dimension lumber from western hemlock pulp logs in Alaska. The recovery reported here would not be attained in Alaska. Most of the Economy grade at the dimension mill or lower grade and salvage items at the stud mill would be chipped in Alaska because of a lack of local markets.

Relative mill efficiency (board feet per cubic foot of lumber) would probably be lower in Alaska. Equipment to assemble a mill to achieve this level of efficiency can be bought from any of several suppliers. The highly skilled millwrights, sawfilers, electricians, and supervisors necessary to maintain this level are generally assembled and trained over long periods. Finally, high recovery sawing does cut volume production slightly and is most common where the cost of logs is very high relative to other production costs.

Cubic scaling was much more closely related to product recovery than was Scribner board-foot scaling. This agrees with past comparisons of long log Scribner scale with log cubic volumes. Cubic scale is an estimate of the cubic volume capable of producing lumber and appears to be an effective estimator of volume and value of lumber and of byproducts.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 cubic foot = 0.02832 cubic meter

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A total of 363 western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) logs from Alaska were sawn to compare recovery at a stud mill and at a dimension mill. Recovery at both mills varied by log diameters and by log scaling system. Lumber grade recovery was primarily in Stud grade at the stud mill and in Standard and Construction grade at the dimension mill. Lumber volume recovery is based on long log Scribner scale and on cubic scale. Lumber recovery was 2.23 times the Scribner volume at the stud mill and 2.05 times the Scribner volume at the dimension mill. The lumber recovery factor was 9.0 at the stud mill and 7.5 at the dimension mill.

Keywords: Lumber yield, lumber recovery, lumber volume, log scaling, western hemlock, *Tsuga heterophylla*, pulpwood logs, dimension lumber, Alaska.

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Logging Damage in Thinned, Young-Growth True Fir Stands in California and Recommendations for Prevention

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Abstract

Aho, Paul E.; Fiddler, Gary; Srago, Mike. Logging damage in thinned young-growth true fir stands in California and recommendations for prevention. Res. Pap. PNW-304. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 8 p.

Logging-damage surveys and tree-dissection studies were made in commercially thinned, naturally established young-growth true fir stands in the Lassen National Forest in northern California. Significant damage occurred to residual trees in stands logged by conventional methods. Logging damage was substantially lower in stands thinned using techniques designed to reduce injuries from felling and skidding. A total of 243 wounded white and red firs in 11 stands were felled, dissected, and analyzed for decay. All wounds were infected by decay fungi. Decay losses associated with wounds were 6.8 and 14.0 percent of the gross merchantable Scribner board-foot volume of the red and white firs sampled, respectively. Wound area and age were most closely related to extent of decay. Volumes of cubic- and board-foot decay are given for wounds of various sizes and ages. Recommendations are made for reducing logging damage to residual trees during thinning operations.

Keywords: Logging damage, young-growth stands, thinning effects, decay (wood), coniferae.

Summary

This paper reports the results of three related studies of logging damage in thinned, young-growth stands of true fir, Douglas-fir, and ponderosa pine in California. Two were of damage surveys made in five stands thinned using conventional logging practices and in four stands logged using procedures designed to reduce damage to residual trees. The third was of tree dissections in 11 true fir stands to relate decay losses to logging wounds. In the five conventionally thinned, young-growth stands surveyed in northern California, 22 to 50 percent of the residual trees were wounded. Of the residual trees in three of the stands, 8 to 15 percent were so badly damaged they were no longer suitable as crop trees. Surveys made in the four stands that were thinned using techniques designed to reduce logging and skidding injuries indicated that damage to residual trees was substantially reduced, ranging from 5 to 14 percent. A total of 199 white and 44 red firs bearing 301 wounds were felled, dissected, and studied in 11 stands in the Lassen National Forest. All wounds examined on the white and red firs were infected by decay fungi. Average age of thinning wounds on the white firs was 13 years. In the white firs, 4.5 percent of the gross merchantable cubic volume and 14.0 percent of the board-foot volumes were lost to decay associated with the wounds. Injury-related decay losses in the red firs were less, but not significantly different.

Present and original wound size and age were the most important characteristics related to amount of decay. Although healed wounds were older than those still open, they had less associated decay. Gouged wounds had more decay than smooth ones, and those in contact with the ground had more decay than those above the ground line.

Tables and the equations used to derive them are presented, so that cubic- and board-foot decay volumes can be determined when present wound area and injury age are known.

The best way to reduce decay losses is to avoid injury to residual trees. Procedures are recommended that will substantially reduce logging damage to residual trees and allow maximum response by the stand to thinning.

Introduction

Observations in several thinned stands of young true fir indicate that significant decay losses are associated with logging wounds, particularly injuries to the lower bole (Maloy 1979), in white fir (*Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr.) and red fir (*A. magnifica* A. Murr.) in northern California. As forest management intensifies, stands will be entered and logged at younger ages, and decay associated with logging damage may lead to serious reductions in projected yields of young-growth fir stands. Forest managers need to know how much volume will be lost to decay associated with logging damage during the period between commercial thinning and harvest and how to prevent or reduce these losses.

Objectives

The primary objectives of these studies were to determine, through surveys of commercially thinned true fir, Douglas-fir, and ponderosa pine stands, the extent of logging-related wounding to residual-crop trees and, through tree dissections in true fir stands, to relate volume of decayed wood to size, age, and position of wounds relative to the ground; to compare decay losses in white and red firs; to determine damage to be expected using current thinning procedures; and to develop guidelines useful in determining allowable levels of damage for marking crop trees and for logging methods to minimize damage to residual stands of young true fir. Another objective was to determine the species of fungi that cause decay associated with logging wounds.

Methods

Selection of Stands

Surveys of logging damage and tree-dissection studies were made in commercially thinned, naturally established young-growth stands in the Lassen National Forest in northern California. Sampling was restricted to stands less than 100 years old that had been commercially thinned 3 to 25 years ago.

Damage Surveys

Surveys were made in stands of true fir, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), and ponderosa pine (*Pinus ponderosa* Laws.) that had been thinned conventionally or by techniques recommended by the Silvicultural Development Unit[1] to reduce damage to residual trees. Plots of 1/40 acre were established at intervals of 1 chain along grid lines 2 to 5 chains apart, depending on the density of the stand. Thus, about 12.5 percent of the total area of the stands was sampled.

Only the best potential crop trees, based on diameter, height, and live-crown ratio in comparison to neighboring trees, in the 1/40-acre plots were examined for logging damage. Logging damage included broken tops and wounds in which bark and cambium were destroyed. In three stands, data were taken on the number of trees that were no longer potential crop trees because of severe logging damage. In two of these stands, the location of wounds on potential crop trees was also noted. Injuries were recorded as basal wounds, if they were in contact with the ground; as bole wounds, if they occurred between the ground line and the base of the live crown; and crown wounds, if they were in the live crown.

Tree Dissection

In each of 11 stands in the Lassen National Forest, 20 to 26 injured white and red fir crop trees were selected for dissection and measurement of tree and decay volumes. Trees selected for dissection were representative of the diameter and crown classes comprising the stand, and all had logging wounds of various sizes and types. Sampling was generally done in active timber sales so that merchantable portions of sample trees could be used.

Before a tree was felled, species, diameter at breast height, and crown class were recorded in addition to the following wound information: height from the ground line to the base of the wound, original and present scar width and length, scar aspect on the tree, and whether it was healed, rough (at least 25 percent of the surface of the injury was gouged), or smooth. The trees were felled and dissected; logs, internal decay, and other defects were measured according to Aho (1977), and the age of trees and wounds determined.

Identification of Fungi Associated With Decay

One or more discolored or decayed wood samples of about 3 cubic inches, depending on the size of the decay column, were taken from behind each injury. Two isolation attempts were made from each sample using aseptic techniques described by Aho (1977) to determine the causal fungi. Hymenomycetous fungi were identified by comparison with known isolates obtained from the Center for Mycology Research at the Forest Products Laboratory, Madison, Wisconsin.

Data Analysis

Cubic and Scribner board-foot volumes were calculated for trees and decay in a computer program (PACUL) on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Data for trees were tabulated by stands, wound types, and decay fungi. Regression analysis was used to determine the relationship among decay (either decay volume or percent of total tree volume) and tree and wound characteristics: age and d.b.h. of the tree and age, size, condition (healed, rough, or smooth), and position of the wound on the tree relative to the ground. Covariance analysis was used to see if differences in decay between red and white fir and between different wound characteristics were significant.

[1] A zone silvicultural unit developing techniques for managing young-growth stands, Region 5 Timber Management, Redding, California.

Results

Table 1—Logging-damage surveys made in stands thinned conventionally

Stand name	Species	Type of logging[1]	Trees sampled	Crop trees damaged[2]	
				Wounded	No longer suitable[3]
			Number	*Percent*	
Battle	White fir	Skidder	813	22	--
Reynolds	Douglas-fir	Tractor	500	35	15
School	White fir	Skidder	719	33	--
Mad	Douglas-fir	Cable	500	46	8
Backgrass	White fir	Grapple skidder	500	50	15

--Data not available.

[1] Skidder logging used rubber-tired vehicles; tractor logging used steel-tracked vehicles.
[2] Logging damage included broken tops and wounds in which the bark and cambium were destroyed.
[3] Crop trees destroyed are included in percent-wounded figures.

Stand Damage Surveys

Damage surveys made in young-growth white fir and Douglas-fir stands thinned conventionally (including by tractor and rubber-tire skidder and by cable) indicated that significant damage occurred to crop trees (table 1). In the five stands sampled, 22 to 50 percent of the crop trees were wounded. In three stands, 8 to 15 percent of the residual trees were either killed or so badly wounded that they were no longer suitable for crop trees. The types of logging injuries to crop trees were noted in surveys made in two true fir stands conventionally thinned using rubber-tire skidders (table 2). The locations of wounds on crop trees were consistent in both stands. Nearly three-quarters of the wounds in both stands were basal, that is, in contact with the ground. Basal wounds are more likely to become infected, and decay is usually more extensive than in wounds higher on trees.

Table 2—Location of wounds on crop trees in two true fir stands thinned conventionally

	Battle stand	School stand
Trees sampled, number	813	719
Trees damaged, number	176	239
Trees damaged, percent	22	33
Basal[1] wounds, percent	74	72
Bole[2] wounds, percent	15	16
Crown[3] wounds, percent	11	12

[1] Basal wounds were those in contact with the ground.
[2] Bole wounds occur from above ground line to the bottom of the live crown.
[3] Crown wounds occur within the live crown.

Table 3—Logging-damage surveys in stands logged using procedures designed to reduce damage to residual trees

Stand name	Species	Type of logging[1]	Crop trees damaged
			Percent
Island	Ponderosa pine	Skidder	5
Red A	White fir	Tractor	11
Red B	White fir	Tractor	11
Red F	White fir	Tractor	14

[1] Skidder logging used rubber-tired vehicles; tractor logging used steel-tracked vehicles.

Surveys made in four young-growth stands thinned using techniques designed to reduce injuries from logging and skidding showed substantial reductions in wounds on crop trees (table 3). Percent of crop trees wounded in these stands ranged from 5 to 14 percent.

Tree-Dissection Studies

Data describing the white and red firs selected for the dissection studies are given in table 4. A total of 199 white and 44 red firs were studied in the 11 stands. Tree ages and sizes (d.b.h. and height) varied widely within stands for each species, but the variation in these characteristics between species was not great. The white firs were, on the average, slightly older and larger than the red firs.

Not counting top damage, 251 wounds were found on the 199 white firs and 50 wounds on the 44 red firs sampled Some were old fire or mechanical wounds not associated with commercial thinning. Other trees had advanced root-rot infections, which also were not associated with thinning wounds. Slightly more than 15 percent of 243 white and red firs sampled had old wounds, broken tops, or root-rot infections. Associated decay losses amounted to 5.4 and 18.1 percent of the cubic and Scribner board-foot volumes of the affected trees, respectively.

On 186 white firs, 231 thinning wounds were found, and 44 occurred on 39 red firs (table 5). Average age of the injuries was 13 years for the white fir and 8 years for the red fir. All were infected by decay fungi. Associated with the wounds was a 4.5 percent loss of the gross merchantable cubic volume and 14.0 percent of the board-foot volume of the white fir trees. Decay accounted for 1.9 and 6.8 percent of the gross merchantable cubic- and board-foot volumes, respectively, of the red fir trees.

Factors Influencing the Amount of Decay Associated With Wounds

Covariance analysis indicated no statistically significant differences in decay associated with wounds between the white and red firs sampled. Therefore, both species were grouped to determine which scar characteristics were significantly related to associated cubic- and board-foot decay volumes. Present and original wound size and age were the most important wound characteristics related to amount of decay. Present wound size explained more variation in decay than did original wound size. Wound age and present size were used in regression analysis to develop equations that can be used to estimate cubic- and board-foot decay losses associated with thinning wounds on true firs.

No statistically significant differences were found in cubic- or board-foot volume of decay among the eight wound aspects tested by covariance analysis. Significant differences occurred in cubic-foot volume of decay and wound condition (healed, smooth, and gouged), but not between board-foot volume of decay and wound condition, probably because of the relatively small number of wounds sampled on sawtimber trees (11.0 inches d.b.h. and larger). Although healed wounds were older than those still open, they had less associated decay. Gouged wounds had the most decay.

Decay was also significantly related to position of the wound relative to the ground; wounds in contact with the ground had more decay than those originating higher in the tree.

Fungi Causing Decay

We attempted to isolate the fungi causing decay in 299 infections in the white and red fir study trees. Decay fungi were isolated from less than 28 percent of the infections (table 6), and more than two-thirds of them could not be identified. Of those identified, *Pholiota limonella* (Pk.) Sacc. was most common.

Table 4—Basic data for wounded trees dissected in 11 stands

Species	Tree basis	Age		D.b.h.		Height	
		Average	Range	Average	Range	Average	Range
	Number	*Years*		*Inches*		*Feet*	
White fir	199	86	39-189	9.6	4.0-20.0	48	18-99
Red fir	44	84	49-131	8.8	4.1-17.4	40	14-98

Table 5—Decay data for thinning wounds in young-growth white and red firs

Species	Tree basis	Total wounds	Wounds infected	Average wound age	Average decay extent		Cubic-foot volume		Scribner board-foot volume	
					Below base of wound	Above top of wound	Gross	Decay	Gross	Decay
	Number		*Percent*	*Years*	*Feet*		*Merchantable*	*Percent*	*Merchantable*	*Percent*
White fir	186	231	100	13	1.6	2.0	2,020.0	4.5	*5,360*	14.0
Red fir	39	44	100	8	1.5	1.0	361.6	1.9	*1,020*	6.8

Table 6—Number of infections and associated decay volumes by fungi isolated from wounded white and red firs

Decay fungus	Infections		Cubic-foot volume		Scribner board-foot volume	
	Number	Percent of total	Decay	Percent of total	Decay	Percent of total
Pholiota limonella (Pk.) Sacc.	19	6.4	8.3	7.5	76	8.7
Heterobasidion annosum (Fr.) Bref.	5	1.7	2.9	3.5	21	2.4
Hericium abietis (Weir ex Hubert) K. Harrison	4	1.3	3.6	3.2	70	8.0
Echinodontium tinctorium (Ell. et Ev.) Ell. et Ev.	1	.3	1.3	1.2	18	2.1
Phellinus pini var. *cancriformans* Larsen, Lombard, et Aho	1	.3	.5	.4	--	--
E. tinctorium & *Pholiota limonella*	1	.3	1.6	1.5	--	--
Unidentified basidiomycetes	49	16.4	15.6	14.0	101	11.6
None	219	73.3	76.4	68.7	585	67.2
Total	299	100.0	111.2	100.0	871	100.0

[1] No board-foot decay volume because infection was in a pole-sized tree.

Table 7—Cubic volume of decay by age and area of thinning wounds in second-growth white and red firs in northern California[1]

Wound age	Volume of decay when area square foot of wound is:					
	0.0	1.0	2.0	3.0	4.0	5.0
Years	*Cubic feet*					
5	0.0	0.2	0.5	0.8	1.1	1.4
10	.0	.3	.6	.9	1.2	1.5
15	.1	.4	.7	1.0	1.3	1.6
20	.3	.6	.9	1.2	1.4	1.7
25	.4	.7	1.0	1.3	1.6	1.9

[1] See Appendix for equation 1 used to derive this table.

Table 8—Scribner board-foot volume of decay by age and area of thinning wounds in second-growth white and red firs in northern California[1]

Wound age	Volume of decay when area square foot of wound is:					
	0.0	1.0	2.0	3.0	4.0	5.0
Years	*Board feet*					
5	0	3	7	10	13	16
10	3	6	9	12	15	18
15	5	8	11	15	18	20
20	8	11	14	17	20	23
25	10	13	16	19	23	26

[1] See Appendix for equation 2 used to derive this table.

Decay Volume in Relation to Wound Age and Area

Multiple regression analysis indicated that cubic- and board-foot decay volumes were significantly related to wound age and original or present wound area for white and red firs. Volume and percent of cubic- and board-foot decay that can be expected for wounds of various sizes and ages are given in tables 7 and 8. Wound area in these tables is based on the present wound dimensions because it was statistically more closely related than original wound size to the amount of associated decay. Wound area in these tables was computed by multiplying the length by the width of the wound inside the callus growth (measures the open face of the wound, not including the part that had healed). The total length and width of the wound at its widest points were measured.

Average decay volumes when wound area and age are known are shown in tables 7 and 8 for young true firs less than 20 inches d.b.h. The equations used to derive the tables are presented in the Appendix.

Commercial thinning is an intensive forest-management tool commonly used in northern California to increase productivity of true fir stands. Extensive damage to residual trees is being caused by conventional logging procedures. Many residual trees are so badly damaged that they are no longer potential crop trees. A high percentage of wounds are in contact with the ground; this is particularly serious because much of the value (both quantity and quality) in a tree is in the butt log.

The best way to reduce decay losses associated with thinning wounds is to avoid injury to residual trees. Our damage surveys in stands thinned conventionally and in those thinned using procedures designed to reduce damage indicate that many wounds can be prevented. Some of these procedures have been described elsewhere (Gravelle 1977). The following procedures can be used to reduce logging damage to residual trees:

Harvest Preparation

- Restrict the logging season. Do not allow logging during the spring and early summer when sap is flowing and bark is loose. Trees are easier to wound, and injuries are often larger.

- Restrict size and type of logging equipment. Match the logging system to the topography. Use cable systems on slopes steeper than 35 percent. On more gentle terrain, track-laying or rubber-tire skidding vehicles can be used. Match size of logging equipment to size of material being removed, spacing of crop trees, and skid-trail width.

- Mark the residual trees. Marking crop trees makes them easier to see and avoid.

Lay out skid roads in advance of log-
ing. This is one of the best ways to re-
uce logging damage. Skid trails
hould not be cleared wider than the
kidding vehicle, preferably not wider
han about 8 feet.

Use straight-line skid-trail patterns.
harp turns should be avoided. Straight
kid trails minimize skidding distance.

Leave buffer ("bump") trees. When
ossible, leave cull logs and bump
ees along the edges of skid trails.
emove bump trees during the last
urn.

Limit log length. Skidding long logs
r the whole bole increases the probabil-
y of damage to residual trees. Log
ength should be related to the spacing
f the residual stand.

ale Administration

Communicate desired results to the
ontractor through training and super-
ision. Convince operators that dam-
ge to residual trees is unnecessary
nd will not be tolerated.

Fell and skid trees on skid roads
efore cutting other timber; otherwise,
allers have trouble finding the skid
ails and felling the timber to lead. Cut
tumps in skid trails as low as possible,
or 4 inches, to prevent the skidder
rom being shunted sideways into resid-
al trees.

- Use directional felling. Fell trees toward or away from skid trails to reduce skidder maneuvering and load pivoting.

- Limb, top, and buck trees before skidding. Limb flush to the tree bole.

- Do not thin stands of thin-barked species too heavily. Young trees and thin-barked species, such as true firs and hemlocks, should not be thinned so heavily that release shock or sunscald results.

- Treat stumps for protection against *Heterobasidion* [= *Fomes annosus*] *annosum* (Fr.) Bref. Where annosus root-rot hazard is high, stumps of pines, true firs, and hemlocks should be treated as soon as possible after trees are felled.

In summary, excessive damage can occur in stands harvested improperly. Data presented here can be used to determine the extent of decay associated with logging wounds, when size and age of wounds are known. Because no chemical or biological methods are available for protecting wounds on living trees from infection by decay fungi, significant volume losses will result. The best control is prevention. Applying our recommendations will result in residual stands with minimal damage, capable of responding to the management treatment.

Metric Equivalents

1 inch = 2.54 cm
1 foot = 0.3048 m
1 chain = 20.117 m
1 cubic foot = 0.028 32 m^3
1 acre = 0.4047 ha
breast height = 4.5 feet = 137.2 cm

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Appendix

Decay-Estimating Equations

The following multiple regression equations estimate cubic and Scribner board-foot decay volumes when wound area and age are known. Wound area was computed by multiplying the present width and length at their longest and widest points within the callus tissue. Scribner board-foot volume was calculated from a stump height of 6 inches to a merchantable-top diameter inside bark of 6 inches. For cubic volume, the top d.i.b. was 4 inches.

Table 7 was derived from equation 1 and table 8 from equation 2.

Cubic-Foot Volume Equation

$$Pc = -0.23 + 0.025\ (A) + 0.29\ (B)$$
$$R^2 = 0.41 \quad Sy{\cdot}x = \pm 0.63 \quad N = 276 \qquad (1)$$

Scribner Board-Foot Volume Equation

$$Pb = -2.25 + 0.49\ (A) + 3.15\ (B)$$
$$R^2 = 0.25 \quad Sy{\cdot}x = \pm 13.47 \quad N = 92 \qquad (2)$$

Where:

Pc = cubic-foot decay volume;
Pb = board-foot decay volume;
A = wound age in years;
B = wound area in square feet;
R^2 = the coefficient of determination or the amount of variation in decay that is explained by the variables in the equations;
$Sy{\cdot}x$ = the standard deviation about regression; and
N = the sample size.

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Logging-damage surveys and tree-dissection studies were made in commercially thinned, naturally established young-growth true fir stands in the Lassen National Forest in northern California. Significant damage occurred to residual trees in stands logged by conventional methods. Logging damage was substantially lower in stands thinned using techniques designed to reduce injuries from felling and skidding. A total of 243 wounded white and red firs in 11 stands were felled, dissected, and analyzed for decay. All wounds were infected by decay fungi. Decay losses associated with wounds were 6.8 and 14.0 percent of the gross merchantable Scribner board-foot volume of the red and white firs sampled, respectively. Wound area and age were most closely related to extent of decay. Volumes of cubic- and board-foot decay are given for wounds of various sizes and ages. Recommendations are made for reducing logging damage to residual trees during thinning operations.

Keywords: Logging damage, young-growth stands, thinning effects, decay (wood), coniferae.

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Avifauna Associated With Early Growth Vegetation on Clearcuts in the Oregon Coast Ranges

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Abstract

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This paper provides estimates of bird density, diversity, and evenness on 13 clearcut units of the Siuslaw National Forest in the Coast Ranges of Oregon, sampled during 1979, 1980, and 1981. Total density of nesting birds ranged from 322 to 588 per 40.5 hectares (100 acres); there were 15 to 19 species nesting on each site.

Keywords: Bird habitat, population distribution, clearcutting, Oregon (Coast Ranges), Coast Ranges—Oregon.

Introduction

The Oregon Coast Ranges is one of the most heavily logged regions of North America (Beuter and others 1976, Williamson 1973). The usual method of logging in the Coast Ranges involves cutting all standing trees—clearcut logging. Commercial species, primarily Douglas-fir, are removed, and noncommercial hardwoods are usually left lying on the site (see "Study Sites" for a detailed description of silvicultural procedures).[1] Timber harvesting in the Oregon Coast Ranges thus results in a dramatic alteration of habitats used by wildlife.

An increasing demand for timber products, coupled with improved planting stocks and silvicultural techniques, has resulted in shorter rotation periods (the time between successive harvests of a stand) and a greater proportion of total area in relatively early stages of succession (Beuter and others 1976). It is thus essential that an understanding of the animal communities associated with these clearcuts be developed. Knowledge must be gained that not only identifies species characteristic of clearcuts but also quantifies use of clearcuts by species usually associated with mature stands. In this way, forest wildlife biologists can better predict the effects that clearcut logging and shorter rotations will have on wildlife of the region. Few studies, however, have documented the animal communities on clearcuts in the Oregon Coast Ranges.

In this paper we report on the use of clearcuts by birds. Our specific objectives were to: (1) describe the avifauna nesting in early growth vegetation on 13 clearcuts and (2) quantify the use of clearcuts by birds not usually associated with clearcuts. This analysis will enhance understanding of the avian community structure of clearcuts, serve as a data base for the formation of hypotheses during future studies that examine the change in species composition through various successional stages and management practices, and provide insight about the ability of species inhabiting mature and old-growth forest to compensate for habitat alteration by using clearcuts for various activities.

[1] Scientific names for birds and plants are listed on pages 9 and 10.

Literature Review

It is not our intent to review all literature on avian communities associated with clearcuts. Studies dealing with the Pacific Northwest are mentioned below and throughout the text. We list other articles with the hope that this information will aid others in assembling relevant literature; literature cited in these papers offers a further source of material.

There are few major field studies dealing with clearcut logging and avian communities in the Pacific Northwest. Hagar (1960) compared the avifauna of several early growth clearcuts with birds of mature forests in the Douglas-fir region of northwestern California and found that species usually associated with weed and brush seral stages were favored by logging; species requiring mature forests were eliminated when larger trees were removed. In the Puget Sound region of western Washington, Manuwal and Munger found that the brush-dominated stages after clearcut logging had higher total density and diversity of birds than uncut stands had.[2] Here again, species usually associated with mature forests were eliminated (as breeding species) by logging. Mannan (1977) and Mannan and others (1980) compared the avifauna of stands that received various silvicultural treatments (clearcut logging, thinning) in the Oregon Coast Ranges. Total bird density on clearcuts was nearly equal to that in natural Douglas-fir stands 35 to 100 years old but was characterized by ground- and brush-nesting species. Hagar (1960), Mannan (1977), Mannan and others (1980), and Manuwal and Munger (see footnote 2) concluded that the severe reduction in snags by clearcut logging practices greatly reduced the number of primary cavity nesters (for example, woodpeckers) and secondary cavity nesters (bluebirds) on clearcuts.

[2] Manuwal, David A.; Munger, Garet. The effect of timber harvest on bird populations in the Douglas-fir forests of Washington State. Unpublished report on file at the University of Washington, Seattle; 1978.

Study Sites

From known distributions and habitat requirements, Meslow and Wight (1975) and Wight (1974) listed birds likely to be found in different successional stages west of the Cascade Range. Both articles discuss the relative use of, and activity patterns on, various seral stages (including clearcuts) in western Oregon. Although these papers give a useful and much needed description of species occurrences, the information is too general to help forest wildlife biologists quantify the use of clearcuts by birds in the Oregon Coast Ranges.

The effect of clearcut logging on avian communities has received more attention in areas outside the Pacific Northwest. Some of these studies and their general geographical locations include: coniferous forests in the Rocky Mountains and the Southwest—Austin and Perry (1979), Franzreb (1977, 1978), Franzreb and Ohmart (1978), Ramsden and others (1979), and Szaro and Balda (1979a, 1979b); coniferous, mixed-conifer, and hardwood forests in the East and Southeast—Conner and Crawford (1974), Conner and Adkisson (1975), Conner and others (1975, 1979), Michael and Thornburgh (1971), Strelke and Dickson (1980), Titterington and others (1979), and Webb and others (1977); and aspen forests of the intermountain west—DeByle (1981). Articles dealing with the various biological, sociological, and economic issues of clearcut logging include Hooven (1973), Pengelly (1972), Marks and Bormann (1972), and Resler (1972). Finally, we suggest that forest wildlife biologists review Lack (1933) for one of the first discussions of the relation between forestry practices and avian habitat selection.

This study was conducted on 13 clearcuts in the Douglas-fir region of the Oregon Coast Ranges on land administered by the USDA Forest Service, Siuslaw National Forest, Alsea and Hebo Ranger Districts. This region is characterized by subclimax Douglas-fir and climax western hemlock and western redcedar; stands are being converted to near monotypes of Douglas-fir after logging. A thorough description of the forest composition, successional patterns, and various environmental features of this region is given by Franklin and Dyrness (1973).

The specific locations and general topography of all study sites are given in table 1. The selection of clearcuts was based on the following: (1) a minimum size of 20 hectares and (2) clearcuts of early growth and vegetation considered "typical" by Forest Service personnel. All sites were clearcut logged (all commercial and noncommercial trees were cut). After logging, sites were prepared for planting by broadcast burning. Douglas-fir seedlings were then hand planted over an entire site at about 3- by 3-meter spacing. At the time of the study, sites ranged from 4 to 9 years in postplanting age, and precommercial thinning had not yet taken place. Thinning usually takes place 10 to 15 years after planting. During precommercial thinning, deciduous trees and less vigorous conifers are felled to increase the spacing between the remaining conifers. Certain sites received aerial herbicide treatment 4 to 5 years after planting to reduce competition for conifer seedlings from shrubs and deciduous trees. Sprayed and unsprayed (control) study sites were also used for an examination of the effects of herbicide treatment on avian community structure. Although herbicides suppressed shrub growth for a period, plant composition was not markedly different between sprayed and unsprayed sites (Morrison 1982). These results represent a sampling of sites and silvicultural practices likely to be encountered on clearcuts in the Oregon Coast Ranges (rather than only sprayed or unsprayed areas).

For a detailed description of the vegetation on each site, see Franklin and Dyrness (1973). All sites were selected according to obvious structural similarities, and a general description of vegetation structure and species composition follows.

Vegetation was characterized by a dense and ubiquitous shrub layer (40 to 75 percent total cover) dominated by salmonberry, thimbleberry, vine maple, and salal. Dominants in the low shrub-herb layer included swordfern, bracken fern, tansy ragwort, foxglove, pearly everlasting, Oregon oxalis, and various grasses. With an average height of less than 2.0 meters, Douglas-fir had not yet assumed a position of dominance (less than 10 percent cover) on most sites. Red alder provided the only significant vertical structure on the sites. Most alder, ranging up to 8.0 meters in height, were concentrated in gullies and areas of soil disturbance.

Table 1—Description of 13 clearcuts in the Coast Ranges of Oregon

Site number[1]	Site size	Elevation	Aspect	Plantation age	Years censused	Location
	Hectares	*Meters*		*Years*[2]		
3403-51	21	300-450	NE	5, 6, 7	1979, 1980, 1981	Lincoln County, Oregon (T. 14 S., R. 9 W.; sec. 14 and 23)
3404-51	24	150-370	NE-SE	4	1979	Lincoln County, Oregon (T. 15 S., R. 10 W.; sec. 4 and 5)
3502-16	31	110-280	NE	7	1979	Lane County, Oregon (T. 15 S., R. 9 W.; sec. 17)
3501-41	26	220-310	NE	7	1979	Lane County, Oregon (T. 15 S., R. 10 W.; sec. 21 and 28)
3503-40	21	300-530	S-N	5	1980	Lane County, Oregon (T. 16 S., R. 9 W.; sec. 5 and 8)
3503-43	25	210-450	SW-NE	6	1980	Lane County, Oregon (T. 16 S., R. 9 W.; sec. 4)
3404-37	26	110-275	S	9	1980	Lincoln County, Oregon (T. 15 S., R. 10 W.; sec. 4)
3401-24	26	220-450	SW	8	1980	Lincoln County, Oregon (T. 14 S., R. 10 W.; sec. 15, 21, and 22)
3503-38	36	150-400	N	4, 5, 6	1979, 1980, 1981	Lane County, Oregon (T. 15 S., R. 9 W.; sec. 31)
1311-165	30	400-530	NW	6	1981	Yamhill County, Oregon (T. 4 S., R. 8 W.; sec. 21)
1304-68	35	350-500	NW-SW	6	1981	Tillamook County, Oregon (T. 3 S., R. 7 W.; sec. 31)
3302-35	24	240-510	NE-SE	7	1981	Lincoln County, Oregon (T. 13 S., R. 9 W.; sec. 34)
3303-14	24	225-300	SW	7	1981	Lincoln County, Oregon (T. 13 S., R. 9 W.; sec. 14)

[1] U.S. Department of Agriculture, Forest Service site designation; on file at Alsea Ranger Station, Alsea, Oregon.
[2] At time of each census, the number of years after planting; most seedlings were planted at 2 years of age.

Methods

Avian Census Technique

The census technique used was the variable circular-plot method (Reynolds and others 1980). Of the 13 study sites, 11 were censused for one season each during 1979, 1980, or 1981; and 2 sites were censused for all 3 years. Ten census stations (fixed sampling points) were established on each site. No station was closer than 100 meters to the clearcut edge, nor closer than 100 meters to the next nearest station. Beginning at sunrise, birds were censused at each station for 8 minutes. Censusing birds at the 10 stations on a site required about 2 hours; only one census was conducted per day. Birds on each site were censused once a week during the peak of the nesting season (May to July) for a total of five censuses a year for each site. Results of these censuses were combined to give an estimate of density for each species per site per year. Bird species diversity (Shannon and Weaver 1949) and evenness (Pielou 1966) were also calculated for each site. Birds soaring over and apparently using a site for foraging (for example, raptors), and birds observed before or after a morning census (but not seen during the census) were not recorded, but the time and location of such birds were noted. The mean number of observations per 40.5 hectares was used as the density estimate for these species. Because study sites were visited only during daylight, nocturnal species (owls) are not considered.

Results and Discussion

Nesting Species

Of the 53 species observed on the clearcuts, 22 were nesting (table 2); however, only 11 of these were considered common or abundant. The nesting bird community typical of clearcuts in the Oregon Coast Ranges is dominated by white-crowned and song sparrows, rufous-sided towhee; rufous hummingbird; orange-crowned, MacGillivray's, and Wilson's warblers; willow flycatcher; and Swainson's thrush. Dark-eyed junco, Bewick's wren, American goldfinch, American robin, wrentit, and black-headed grosbeak were regular but relatively uncommon nesters. Cavity-nesting species were extremely rare on all sites.

All the common to abundant nesting species nest and forage on or near the ground; typically used substrates include various shrubs (salmonberry, thimbleberry, salal), Douglas-fir, and deciduous trees (especially red alder). Shrubs and conifer seedlings were widespread over all sites; they provide ample cover for species preferring low, shrubby habitat (sparrows, towhee, hummingbird, orange-crowned and MacGillivray's warblers). More local in distribution were species that included deciduous trees (red alder, for example) in their habitat. Density of several species, especially the Wilson's warbler, Swainson's thrush, and black-headed grosbeak, appeared to be related to the density of red alder.

Primary and secondary cavity-nesting species were extremely rare as breeding species on all study sites. Seldom did a site have more than 2 to 10 snags of adequate size (>20-30 cm in d.b.h. and >4-6 m in height) to be suitable as nesting sites for most cavity nesters; see Bull (1978), Thomas and others (1979), and Mannan and others (1980). A 30-hectare clearcut would typically support one nesting pair of either hairy woodpecker, western bluebird, or chestnut-backed chickadee; several sites had no nests of cavity-nesting species.

The total density of nesting individuals ranged from 322 to 588 birds per 40.5 hectares (table 3). Species richness ranged from 15 to 19 species per site, diversity from 2.27 to 2.60, and evenness from 0.834 to 0.900. Mannan (1977) found a similar diversity (2.63) for the avian community on 10-year-old clearcuts in the Oregon Coast Ranges. Nonnesting birds were not included in overall density and diversity because of the often sporadic occurrence and varied activities of these species.

For all sites, total density of nesting birds was lower in 1980 compared with 1979 and 1981. Reasons for such variation in density are obscure but may include weather conditions, food availability, observer error, or other factors. Caution should be used if census data are used to make comparisons between sites and years.

Table 2—Estimated density, frequency of occurrence, and abundance of avifauna associated with early growth vegetation in 13 clearcuts in the Oregon Coast Ranges, by activity and species

Activity and species	Birds per 40.5 ha				Frequency of occurrence by census (by site)				Abundance[1/]
	1979	1980	1981	$\bar{X}$	1979	1980	1981	$\bar{X}$	
	Number				*Percent*				
Nesting:									
Willow flycatcher	37.6	12.0	39.7	29.8	84 (100)	87 (100)	100 (100)	90 (100)	C
American goldfinch	49.0	22.5	27.8	33.1	100 (100)	97 (100)	100 (100)	99 (100)	C
Rufous-sided towhee	38.0	29.0	40.7	35.9	100 (100)	100 (100)	100 (100)	100 (100)	C
Dark-eyed junco	23.4	8.5	17.3	16.4	96 (100)	87 (100)	100 (100)	94 (100)	C
White-crowned sparrow	70.8	46.8	47.2	54.9	100 (100)	100 (100)	100 (100)	100 (100)	A
Song sparrow	42.6	43.8	67.7	51.4	100 (100)	100 (100)	100 (100)	100 (100)	A
Bewick's wren	12.5	6.8	6.0	8.4	80 (80)	87 (100)	83 (100)	83 (93)	U
American robin	6.8	3.5	7.7	6.0	84 (100)	90 (100)	100 (100)	91 (100)	U
Swainson's thrush	38.0	47.8	74.7	53.5	84 (100)	100 (100)	100 (100)	95 (100)	A
MacGillivray's warbler	25.0	20.2	29.8	25.0	100 (100)	100 (100)	100 (100)	100 (100)	C
Orange-crowned warbler	43.2	33.0	24.0	33.4	100 (100)	100 (100)	100 (100)	100 (100)	C
Wilson's warbler	23.6	19.2	23.2	22.0	100 (100)	100 (100)	100 (100)	100 (100)	C
Rufous hummingbird	69.4	56.7	39.0	55.0	100 (100)	100 (100)	100 (100)	100 (100)	A
Black-headed grosbeak	6.2	1.5	13.0	6.9	88 (100)	67 (100)	79 (83)	78 (94)	U
Wrentit	7.0	3.3	2.5	4.3	40 (40)	37 (67)	17 (33)	31 (47)	R
Mountain quail	3.5	4.0	4.0	3.8	20 (40)	7 (17)	8 (17)	12 (25)	S
Hairy woodpecker	.4	.2	.2	.3	84 (100)	87 (100)	38 (83)	70 (94)	U
Western bluebird	.3	.2	.2	.3	56 (80)	27 (50)	17 (17)	33 (49)	R
Violet-green swallow	3.0	1.0	1.0	2.0	16 (20)	13 (33)	13 (33)	14 (29)	S
Common nighthawk	.2	.1	—	.1	12 (20)	13 (17)	— —	8 (12)	R
Tree swallow	.2	—	.2	.2	16 (20)	— —	17 (17)	11 (12)	S
Chestnut-backed chickadee	1.0	1.5	2.0	1.5	8 (20)	27 (50)	63 (83)	33 (51)	U
Foraging:									
Warbling vireo	4.0	—	—	4.0	20 (40)	— —	— —	7 (13)	S
Sharp-shinned hawk	.2	.2	—	.2	4 (20)	4 (17)	— —	3 (12)	S
Band-tailed pigeon	5.5	5.0	9.0	6.5	24 (40)	13 (33)	13 (17)	17 (30)	U
Common flicker	.2	.1	.1	.2	92 (100)	60 (83)	25 (67)	59 (83)	U

Table 2—Estimated density, frequency of occurrence, and abundance of avifauna associated with early growth vegetation in 13 clearcuts in the Oregon Coast Ranges, by activity and species—(continued)

Activity and species	Birds per 40.5 ha				Frequency of occurrence by census (by site)				Abundance[1]
	1979	1980	1981	$\bar{X}$	1979	1980	1981	$\bar{X}$	
	Number				*Percent*				
Foraging (continued):									
Yellow-bellied sapsucker	.1	.1	—	.1	12 (60)	7 (33)	— —	6 (31)	S
Downy woodpecker	.1	.1	—	.1	16 (60)	10 (33)	— —	9 (31)	S
Olive-sided flycatcher	2.0	1.0	1.0	1.3	56 (100)	43 (67)	8 (33)	36 (67)	R
Steller's jay	4.6	2.8	2.3	3.2	72 (100)	63 (100)	17 (67)	51 (89)	R
Winter wren	2.0	1.5	—	1.8	28 (80)	13 (50)	— —	14 (43)	S
Purple finch	3.7	2.0	—	2.9	32 (60)	13 (33)	— —	15 (31)	S
Pine siskin	4.0	4.0	—	4.0	12 (40)	7 (17)	— —	6 (19)	S
Cedar waxwing	3.0	4.0	7.3	4.8	24 (80)	23 (67)	13 (67)	20 (71)	R
Western wood pewee	1.0	1.0	1.0	1.0	4 (20)	13 (17)	8 (33)	8 (23)	S
Pileated woodpecker	.2	.1	.2	.2	8 (20)	17 (50)	8 (33)	11 (34)	S
Yellow warbler	2.0	—	—	2.0	8 (20)	— —	— —	3 (7)	S
Red-tailed hawk	.2	—	—	.1	4 (20)	— —	— —	1 (7)	S
Black-capped chickadee	2.5	—	2.0	2.3	4 (30)	— —	8 (33)	4 (18)	S
Common bushtit	2.5	2.0	—	2.3	8 (20)	4 (17)	— —	4 (12)	S
Rough-winged swallow	2.0	—	—	2.0	8 (40)	— —	— —	3 (13)	S
Turkey vulture	1.0	1.0	2.0	1.3	16 (60)	17 (50)	8 (17)	14 (42)	S
Cooper's hawk	—	.2	.2	.2	— —	4 (17)	8 (17)	4 (11)	S
Perching (activity unknown):									
Brown-headed cowbird	4.0	3.5	4.0	3.8	8 (20)	23 (33)	4 (17)	12 (23)	S
Townsend's solitaire	1.3	—	—	1.3	16 (60)	— —	— —	5 (20)	S
Brewer's blackbird	1.0	—	—	1.0	4 (20)	— —	— —	1 (7)	S
Evening grosbeak	3.0	3.0	—	3.0	36 (80)	23 (50)	— —	20 (43)	S
Western tanager	2.0	1.7	3.0	2.2	12 (20)	20 (50)	4 (17)	12 (29)	S
Hermit warbler	3.0	1.0	—	2.0	8 (20)	13 (17)	— —	7 (12)	S
Black-throated gray warbler	3.0	—	—	3.0	16 (40)	— —	— —	5 (13)	S
Chipping sparrow	2.0	—	—	2.0	4 (20)	— —	— —	1 (7)	S
Hutton's vireo	—	2.0	—	2.0	— —	7 (17)	— —	2 (6)	S
Varied thrush	—	—	1.0	1.0	— —	— —	8 (17)	3 (6)	S

[1] For species with greater than 50-percent occurrence: R (rare) = 1 to 4 birds/40.5 ha; U (uncommon) = 5 to 15; C (common) = 16 to 40; A (abundant) = >41. For species with less than about 50-percent occurrence: S (sporadic) = (any density).

Table 3—Density, diversity, evenness, and species richness of birds nesting on clearcuts of early growth timber in the Oregon Coast Ranges, by site number

Site number[1]	Year censused	Density	Number of species[2]	Diversity[2]	Evenness[2]
		Birds per 40.5 hectares			
3403-51	1979	551	16	2.41	0.870
3403-51	1980	334	15	2.35	.867
3403-51	1981	588	16	2.38	.859
3404-51	1979	552	18	2.60	.900
3502-16	1979	482	19	2.57	.874
3501-41	1979	376	16	2.36	.852
3503-40	1980	361	16	2.39	.863
3503-43	1980	326	16	2.31	.834
3404-37	1980	393	16	2.39	.863
3401-24	1980	376	15	2.27	.838
3503-38	1979	488	16	2.42	.893
3503-38	1980	322	16	2.36	.873
3503-38	1981	556	16	2.43	.877
1311-165	1981	476	16	2.36	.852
1304-68	1981	380	17	2.45	.866
3302-35	1981	410	15	2.40	.886
3303-14	1981	396	15	2.31	.852
$\bar{X}$		433	16	2.40	.867
Standard deviation		88.8	1.1	.08	.020

[1] U.S. Department of Agriculture, Forest Service site designation; on file at Alsea Ranger Station, Alsea, Oregon.

[2] Pielou (1966).

Regularly Observed Species

Many birds regularly encountered on the sites usually nested in adjacent mature stands and used clearcuts for various other activities, especially foraging. Notable in this category were cavity-nesting birds, including hairy and downy woodpeckers, common flicker, yellow-bellied sapsucker, and chestnut-backed chickadee. The pileated woodpecker, a species usually associated with mature and old-growth forests (Bull and Meslow 1977), was observed foraging on down logs on several sites. The black-capped chickadee, which apparently nests in the lower foothills of the Oregon Coast Ranges, sporadically visited clearcuts at higher elevations, especially during the nonnesting season. Other species, including the Steller's jay, purple finch, band-tailed pigeon, cedar waxwing, olive-sided flycatcher, and evening grosbeak were also observed foraging and perching, but not nesting, on clearcuts.

Several of the species listed as "Perching (activity unknown)" or "Foraging" in this study have been observed nesting on clearcuts in the Oregon Coast Ranges—Mannan (1977) recorded the infrequent nesting of the common bushtit, Townsend's solitaire, and house wren on the 10-year-old sites he studied.

Occasionally Observed Species

Birds in this final category were a minor component (by density) of clearcuts in the Oregon Coast Ranges. Included here are the raptorial species, all of which were observed actively foraging over the clearcuts (as opposed to simply flying directly over an area). The sharp-shinned, Cooper's, and red-tailed hawks were seen flying about or perched on the sites only infrequently. Turkey vultures were more common visitors to clearcuts than the hawks, foraging over several sites each year.

The remaining species in this category were mostly passerines that usually nested in surrounding habitats. Included were the warbling and Hutton's vireos; winter wren; brown-headed cowbird; Townsend's solitaire; Brewer's blackbird; pine siskin; western wood pewee; yellow, hermit, and black-throated gray warblers; chipping sparrow; western tanager; common bushtit; and rough-winged swallow. Although brown-headed cowbirds were observed on the clearcuts, the rate of nest parasitism by this species was not assessed.

Avian communities associated with early growth clearcuts in the Oregon Coast Ranges are characterized by species that apparently prefer a shrub-dominated habitat (sprarrows, towhee, certain warblers); such species should be expected as regular nesters on all clearcuts. Where deciduous trees are present, such as in gullies, wet depressions, and along logging roads, species that utilize the vertical structure provided by deciduous trees are found (Wilson's warbler, Swainson's thrush, black-headed grosbeak). Deciduous trees increase both the vertical and horizontal patchiness or heterogeneity of vegetation structure on clearcuts and allow utilization of the sites by a greater number of individuals of certain species compared with sites lacking deciduous trees.

Several authors have recommended that a minimum of 5 or 6 snags per hectare are required to maintain a nesting population of most primary and secondary cavity nesters on an area (Balda 1975; Cunningham and others 1980; Scott 1979; Thomas and others 1979, table 18). Mannan and others (1980) suggested 11 snags per hectare (>48 cm in d.b.h., >4.4 m in height) as an optimum density of snags, indicating that even 6 snags may be insufficient to maintain functional populations of cavity-nesting species in the forest ecosystem (to maintain their role in insect predation). It is thus significant that clearcuts in this study had only about 0.3 snag per hectare. Similarly, Cline and others (1980) found a mean density of 0.5 snag (>9 cm in d.b.h.) per hectare in 10-year-old clearcuts in the Oregon Coast Ranges.

n summary, the following actions could ncrease the numbers and kinds of birds esting on clearcuts:

. Maintain patches of deciduous trees for example, red alder, bigleaf maple, lderberry). Appropriate places for reten- on of deciduous trees would be along ogging roads and landings, in wet de- ressions and areas of unstable soils, nd along permanent and intermittent (all lasses) stream courses, where conifers re often difficult to establish. Patches nay be relatively small in area (5 to 10 m y 10 to 20 m; Morrison 1982).

2. Retain snags during logging operations whenever possible; killing and leaving arge culls instead of felling them may be ecessary. Although the minimum num- er of snags required was not directly ssessed in this study, literature available ndicates that 6 snags (>20 to 30 cm in d.b.h., >4-6 m in height) per hectare should be provided on each clearcut, 1 snags may be more appropriate. Data resented in Thomas and others (1979) or eastern Oregon and Washington rovide general guidelines for snag anagement on a species-specific basis nat can be followed until similar informa- on is available for western Oregon orests.

. Leave large (>20-30 cm in d.b.h.), own material (logs) scattered about ach site to serve as foraging substrate or woodpeckers and other birds. In ddition, various species of amphibians, eptiles, and mammals use logs (Maser nd others 1979).

ctions such as these increase the iversity of habitats available for birds nd will enhance both species richness nd diversity of avian communities on learcuts.

Common name	Scientific name
Birds:[3]	
Turkey vulture	*Cathartes aura*
Sharp-shinned hawk	*Accipiter striatus*
Cooper's hawk	*Accipiter cooperii*
Red-tailed hawk	*Buteo jamaicensis*
Mountain quail	*Oreortyx pictus*
Band-tailed pigeon	*Columba fasciata*
Common nighthawk	*Chordeiles minor*
Rufous hummingbird	*Selasphorus rufus*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Pileated woodpecker	*Dryocopus pileatus*
Northern flicker	*Colaptes auratus*
Hairy woodpecker	*Picoides villosus*
Downy woodpecker	*Picoides pubescens*
Western wood-pewee	*Contopus sordidulus*
Olive-sided flycatcher	*Contopus borealis*
Willow flycatcher	*Empidonax traillii*
Violet-green swallow	*Tachycineta thalassina*
Tree swallow	*Tachycineta bicolor*
Northern rough-winged swallow	*Stelgidopteryx serripennis*
Steller's jay	*Cyanocitta stelleri*
Black-capped chickadee	*Parus atricapillus*
Chestnut-backed chickadee	*Parus rufescens*
Bushtit	*Psaltriparus minimus*
Wrentit	*Chamaea fasciata*
Bewick's wren	*Thryomanes bewickii*
Winter wren	*Troglodytes troglodytes*
House wren	*Troglodytes aedon*
Townsend's solitaire	*Myadestes townsendi*
American robin	*Turdus migratorius*
Swainson's thrush	*Catharus ustulatus*
Varied thrush	*Ixoreus naevius*
Western bluebird	*Sialia mexicana*
Cedar waxwing	*Bombycilla cedrorum*
Warbling vireo	*Vireo gilvus*
Hutton's vireo	*Vireo huttoni*
Orange-crowned warbler	*Vermivora celata*
MacGillivray's warbler	*Oporornis tolmiei*
Wilson's warbler	*Wilsonia pusilla*
Yellow warbler	*Dendroica petechia*
Black-throated gray warbler	*Dendroica nigrescens*
Hermit warbler	*Dendroica occidentalis*
Brewer's blackbird	*Euphagus cyanocephalus*
Brown-headed cowbird	*Molothrus ater*
Western tanager	*Piranga ludoviciana*
Black-headed grosbeak	*Pheucticus melanocephalus*
Evening grosbeak	*Coccothraustes vespertinus*
Purple finch	*Carpodacus purpureus*
Pine siskin	*Carduelis pinus*
American goldfinch	*Carduelis tristis*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Dark-eyed junco	*Junco hyemalis*
Chipping sparrow	*Spizella passerina*
White-crowned sparrow	*Zonotrichia leucophrys*
Song sparrow	*Melospiza melodia*

[3]Authority for birds is American Ornithologists' Union (1982).

Common name	Scientific name
Plants:[4]	
Douglas-fir	*Pseudotsuga menziesii* (Mirbel) Franco
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western red cedar	*Thuja plicata* Donn.
Salmonberry	*Rubus spectabilis* Pursh
Thimbleberry	*Rubus parviflorus* Nutt.
Vine maple	*Acer circinatum* Pursh
Salal	*Gaultheria shallon* Pursh
Swordfern	*Polystichum munitum* (Kaulf.) Presl
Tansy ragwort	*Senecio jacobaea* L.
Foxglove	*Digitalis purpurea* L.
Pearly everlasting	*Anaphalis margaritacea* (L.) B. & H.
Oregon oxalis	*Oxalis oregana* Nutt. ex T. & G.
Red alder	*Alnus rubra* Bong.
Aspen	*Populus tremuloides* Michx.
Bigleaf maple	*Acer macrophyllum* Pursh
Elderberry	*Sambuscus racemosa* L.

[4]Authority for plants is Hitchcock and Cronquist (1973).

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English Equivalents of Metric Units

1 hectare = 2.47 inches
1 meter = 39.37 inches
1 centimeter = 0.39 inch

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This paper provides estimates of bird density, diversity, and evenness on 13 clearcut units of the Siuslaw National Forest in the Coast Ranges of Oregon, sampled during 1979, 1980, and 1981. Total density of nesting birds ranged from 322 to 588 per 40.5 hectares (100 acres); there were 15 to 19 species nesting on each site.

Keywords: Bird habitat, population distribution, clearcutting, Oregon (Coast Ranges), Coast Ranges—Oregon.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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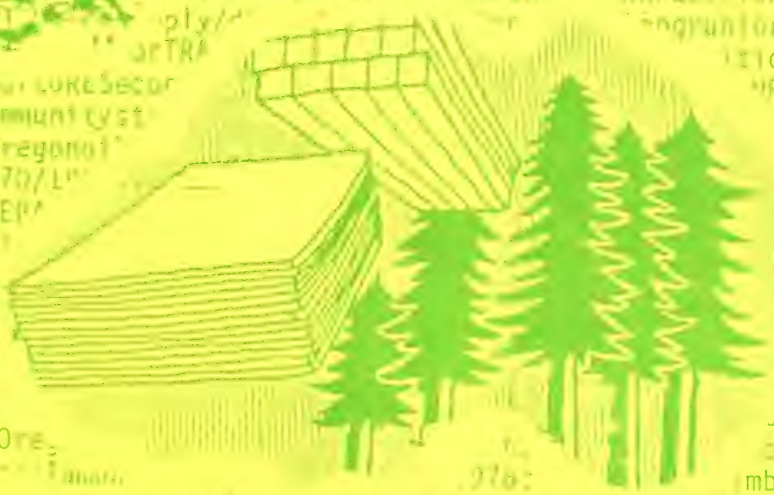
Considering Departures From Current Timber Harvesting Policies:

Case Studies of Four Communities in the Pacific Northwest

Con H Schallau and Paul E. Polzin



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Abstract

Schallau, Con H; Polzin, Paul E. Considering departures from current timber harvesting policies: case studies of four communities in the Pacific Northwest. Res. Pap. PNW-306. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 29 p.

U.S. Department of Agriculture regulations permit departures from current National Forest timber harvesting policies when "implementation of base harvest schedules . . . would cause a substantial adverse impact upon a community . . .." This paper describes the kinds of information needed for forest managers to adequately assess the relevance of the departure issue to particular planning units. The relevance of the departure issue varied, depending on: (1) future timber supply, (2) timber dependency, (3) the long-term feasibility of alternatives to current timber harvesting schedules, and (4) whether or not the growth of industries not dependent on timber might compensate for a timber shortage.

Keywords: National Forest policy, economic impact, economic importance (forests), timber harvesting policy, harvest scheduling, timber supply.

Preface

Traditionally, forest management planning has had a long-term perspective. Public forest management has been predicated on the notion that postwar trends in the demand for timber products will continue indefinitely. A pent-up demand for housing and prospects for expanding foreign markets bode well for timber processors in the Pacific Northwest (Resources for the Future 1982). Consequently, despite the fact that the lumber industry has been suffering from its worst decline in production since World War II, National Forest management planning and priorities will undoubtedly continue to reflect a growing need for timber products.

In this report, we provide a procedure for evaluating past performance and likely future trends in the economies of small communities. We believe this procedure will be useful for analyzing a variety of decisionmaking situations. To illustrate our procedure, we chose a policy issue and examined its potential economic implications. We systematically analyzed the relevance of possible departures from current USDA Forest Service timber harvesting schedules to the economic futures of two communities in western Montana and two in the Douglas-fir region (west side of the Cascade Range) of Oregon.

Analysis of the departure issue involved a supply-side approach. The Forest Service cannot significantly influence demand for forest products for the timespan considered. Furthermore, we focused on differences; we believe timber product demand factors, unlike supply factors, are essentially the same for all four communities.

This report is intended mainly for economists and other policy analysts. Others interested in our approach and its possible use for analyzing other issues or localities may find it useful to read pages 1 to 6, to scan tables 4 to 7 and 19 to 22, then to read pages 25 and 26.

We acknowledge the comments and assistance from numerous individuals who reviewed earlier versions of this paper. Special thanks to Charles Keegan III, University of Montana, for information about the timber products industry of western Montana; and to those who provided data on detailed earnings: Thomas M. Lynch, Oregon Employment Division; Alan R. Mathany, Director, Office of Budgets, Oregon State University; and Paul R. Rafferty, Jr., Montana Division of Labor and Industry.

Introduction

Regulations issued by the U.S. Department of Agriculture in 1979 on land and resource management planning in the National Forest System (USDA Forest Service 1979) provided timber managers with additional flexibility in establishing "harvest schedules." Before 1979, the USDA Forest Service had been adhering to a strict interpretation of sustained yield; that is, nondeclining even flow. Now departures from the "base harvest schedule"[1/] can be considered when "implementation of base harvest schedules . . . would cause a substantial adverse impact upon a community in the economic area in which the forest is located" (USDA Forest Service 1979). The added flexibility, however, could complicate the forest planning process because the merits of base harvest schedules must be evaluated in terms of economic impacts as well as economic efficiency. A line officer who does not believe current policies will cause adverse impacts may, however, ignore the departure (USDA Forest Service 1982).

This paper describes and illustrates a systematic analytical procedure for determining whether a departure should be considered for a particular National Forest planning unit.

1/ "The timber sale schedule in which the quantity of timber planned for sale and harvest for any future decade is equal to or greater than the planned sale and harvest for the preceding decade of the planning period and this planned sale and harvest for any decade is not greater than the long-term sustained yield capacity" (USDA Forest Service 1982).

Fundamental Questions

Our examination of the departure policy is organized around a series of questions about the extent and economic role of an area's timber resource (fig. 1). A "no" to any one of the first three questions suggests that departure from the base harvest schedules—that is, nondeclining even flow (NDEF)—should not be considered:

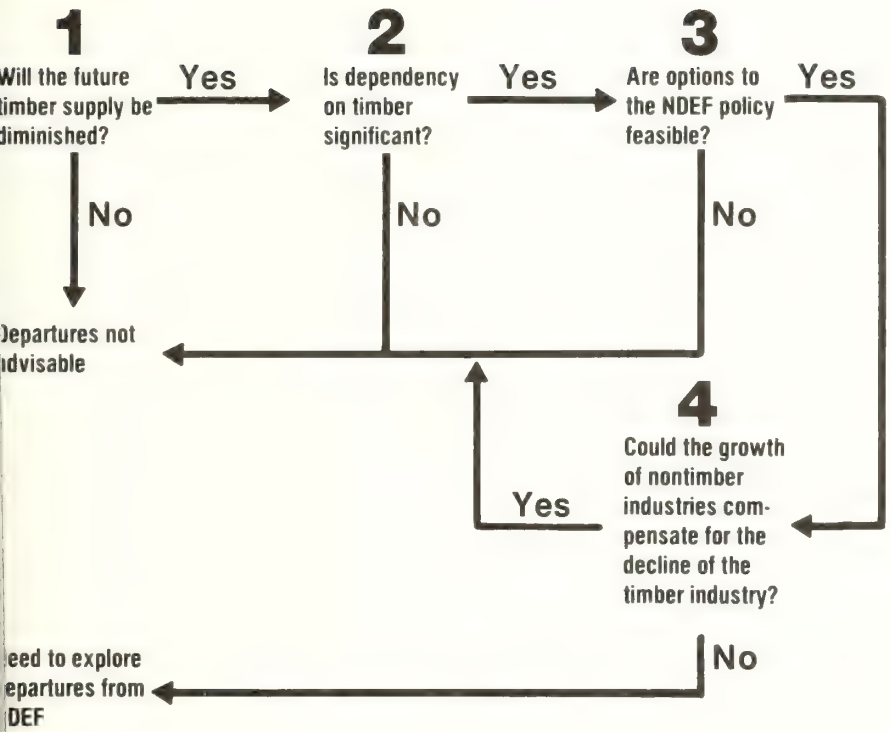
1. Will the future timber supply be diminished? The case for departure is weak if, for the foreseeable future, the area's timber supply will be about equal to the raw material requirements of the processing industry. Despite a balance between timber supply and demand, employment in the wood processing industry may decline as new technology is adopted. Future increase in technology, however, may not precipitate "adverse impacts"[2/] because related employment change has been gradual in the past.

2/ For this paper, an "adverse impact" is any significant and sustained loss of export base jobs and income resulting in the loss of necessary private and public services.

2. Is dependency on timber significant? The economic impact of a shortfall in timber harvesting depends on the importance of the timber industry to the local economy. A community highly dependent on timber, for instance, might be adversely impacted by a modest, but sustained shortfall. A similar decline would have less impact on a community with a more diversified economy.

3. Are options to the nondeclining even flow policy feasible? Timber production is peculiar in that you "cannot tell the product from the machine" (Duerr 1960); that is, until a tree is harvested, it is a wood-making machine. Furthermore, the annual wood production from a tree may have little bearing on when the tree is harvested because the product can be stored on the stump. Most National Forests in the Pacific Northwest contain considerable amounts of stored overmature timber. In some instances, the harvest of this stored wood could be accelerated without jeopardizing the Forest's longrun ability to produce wood (Beuter and others 1976). Elsewhere, however, more rapid rates of harvesting may not be feasible; that is, acceleration of harvesting would deplete current stocks to the point that future availability of timber from the Forest would be jeopardized.

4. Could the growth of nontimber industries compensate for the decline of the timber industry? In the past, a particular timber-dependent community might have been vulnerable to a shortfall in the supply of timber. In the future, however, a new industry or continued industrial diversification could compensate for decline of the timber industry. In such instances, there may be no need to consider departures.



igure 1.—Fundamental questions about the ppropriateness of departing from current mber harvesting policies—nondeclining even ow (NDEF).

In some cases, answering the four fundamental questions is simple. But to explore the departure issue in more detail, we chose examples that require a formal analysis. Our analytical procedure involves three basic components: (1) evaluating the timber supply situation and options to NDEF, (2) identifying the export base industries of an area, and (3) assessing economic trends influencing the growth of each area.

Our evaluation of the timber supply situation and the feasibility of options to the NDEF are based on published reports. We used an export base model to evaluate timber dependency and economic trends.

Growth of Export Base—A Key Element

Most economic growth and change in small regions can be attributed to events outside the area, and changes in the local, nonexport-producing (service or derivative) industries can be traced to changes in industries producing for markets outside the area (export base). Our assessment focuses on past and potential changes in the export base sector of each study area.

The concept of export base industries is straightforward; all economic activities influenced by outside factors are included. Regional analysts have used a number of methods to bifurcate local economies into export base and derivative sectors. For most industries, we have used the assignment approach (direct assignment of specific industries) for deriving estimates of the export base in our four study communities. In addition, we consulted knowledgeable public officials who helped us classify a few industries (for example, miscellaneous food preparation) into the basic or derivative categories. Though simple, this method may be the most appropriate for our communities because all are relatively small, and most of the industries include only a few similar firms that can easily be classified as export base or derivative. Like other bifurcation techniques, however, the assignment approach has drawbacks. Some export activities do not correspond to the Standard Industrial Classification (SIC) codes, developed by the Office of Management and Budget (1972), which we used to assign industries to either the export base or derivative sectors. Portions of the tourist industry are found in retail trade, services, and other SIC categories.[3/] In addition, certain data are not available—there is little information about the incomes of self-employed, health care professionals. In short, the following analysis of the export industries should be interpreted carefully. The figures were derived from several sources, and many are educated guesses. The data, though, are sufficiently reliable that the important characteristics of the local economy can be identified.

The importance of export base industries is best measured by the income earned by workers. These dollars represent a net injection into the economy and create additional income in the derivative industries as they are spent and respent in the local area. To some extent, data on earnings understate the importance of basic industries; they do not include payments by export businesses for utilities and local taxes, or purchases from local merchants. For the most part, these figures are not available. Nonlabor expenditures are discussed later. We have not referenced the number of export base workers—the persons employed in the export industry. Earnings, not the number of export base (or "basic") workers, affect the local economy. It makes little difference whether $20,000 is earned by one basic worker or by two, each making $10,000. Earnings and employment are closely related—more workers usually means more income. But problems may develop in export base industries that have many workers but pay low wages or have few workers and pay very high wages; looking only at employment may overstate or underestimate the importance of these industries to the local economy. On the other hand, earnings data must be adjusted for inflation so that economic activity for different time periods can be compared. To account for inflation, we used the implicit price deflator for personal consumption expenditures to convert current 1970 and 1978 dollars to a constant 1972 base (U.S. Department of Commerce, Bureau of Economic Analysis 1979).

Long-Term Trends—The Principal Focus

A snapshot of a ball tossed into the air does not disclose whether the ball is going up or down. Likewise, we cannot assess a community's future economic performance by examining only the current situation. We must investigate past trends to gain a proper perspective.

Short-term trends in timber-related industries usually coincide with the national business cycle (Wall 1972). These short-term cycles (averaging about 40 months) may mask protracted changes in both the timber industry and the dependent economies. To avoid misinterpretation of short-term phenomena, we discuss changes over a longer period (the mid-1960's to 1978).[4/]

The first step in our analysis of trends is an assessment of prospects for economic growth, as they may have appeared in 1970, for each study area. We present a variety of forecasts published during the late 1960's. We then compare actual change in economic activity between 1970 and 1978 with these earlier forecasts. This comparison will help identify persistent trends, as well as any apparent short-term aberrations. Finally, for each study area, we assess the prospects for growth during the 1980's and the possible need to consider departures from the nondeclining even flow policy.

[3/] Using employment data and a different bifurcation approach, Schuster (1980) identified the economic base of Montana and five multicounty areas. He found that the "recreation industry" accounts for about 9 percent of Montana's nonagricultural export base.

[4/] Our analysis is based on economic data for 1970 and 1978, which correspond to different phases of the national business cycle. Specifically, 1970 was not as good a year as 1978 for the wood products industry. Comparable phases of the business cycle should be analyzed, but this information was not available when we initiated this study. Because of the long-term focus of our study, we do not believe this deficiency affects our conclusions.

Comparison of Four Timber-Dependent Communities

Timber-dependent communities in the West represent a wide range of circumstances—high dependency on timber and an adequate timber supply, moderate dependency but an uncertain timber supply, and so forth. Consequently, NDEF does not have the same implications for all communities. For this reason, we chose four communities representing a diverse set of circumstances. As seen in figure 2, two of the areas are located west of the divide in Montana (Flathead and Missoula), and two are located in the Douglas-fir region (west side of the Cascade Range) of Oregon (Linn-Benton and Douglas).

The county is the smallest jurisdiction for which reliable earnings and employment data are available. Three of the four study areas are single counties. Linn and Benton Counties are combined because of geographical proximity, functional interdependence, and short commuting distances. Despite the restriction of countywide data, we believe each community corresponds to a functional economic area, representing a unique commuting and shopping zone as well as a local labor market and service area.[5/]

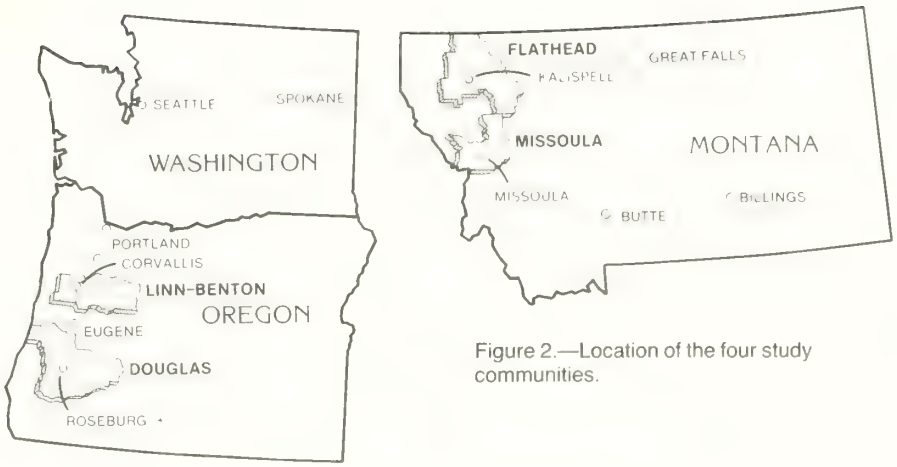


Figure 2.—Location of the four study communities.

Economic Overview of the Timber-Dependent Communities in 1970

The wood products industry was an important contributor to the economy of each study community in 1970. Dependency on timber is not, however, the only way to characterize a local economy. In this section, we examine general indicators of the economy (population, per capita income, nonfarm earnings) to provide an overview of each community.

The population figures presented in table 1 show that the communities are not equal in size. Linn-Benton is by far the largest; Douglas is second; Missoula, third; and Flathead, fourth. The largest of the timber-dependent communities (Linn-Benton) is more than three times larger than the smallest (Flathead).

Unlike for the national economy, there are no comprehensive indexes of economic activity, such as gross national product, for States and counties. Nonfarm earnings is often used as a measure of economic activity for small areas; it consists of wages and salaries, proprietors' income, and other income of all working persons, except those employed in agriculture. In most cases there is a high correlation between economic activity and the amount of labor required to produce it. As shown in table 1, the two Oregon communities are much larger than their Montana counterparts when measured by nonfarm earnings.

The larger population and nonfarm earnings in Oregon do not necessarily reflect the relative economic well-being of Montana and Oregon residents. Although there is no accurate measure of well-being, per capita income is a widely used indicator and 1970 figures for the study communities are presented in table 1. There is relatively little variation in per capita income among the four communities; only a 10-percent difference distinguishes the highest (Missoula) and the lowest (Linn-Benton).

Table 1—A comparison of population, nonfarm earnings, and per capita income of 4 timber-dependent communities in Montana and Oregon, 1970

Community	Population	Nonfarm earnings	Per capita income[1/]
		Thousand 1972 dollars	1972 dollars
Montana:			
Flathead	39,460	95,591	3,439
Missoula	58,263	167,239	3,594
Oregon:			
Linn-Benton	125,495	315,775	[2/]3,298
Douglas	71,743	201,005	3,464

[1/] Per capita income was derived from total personal income of residents, which is the income from all sources, including nonfarm earnings.

[2/] Weighted average for Linn and Benton Counties.

Source: U.S. Bureau of Economic Analysis, Regional Economic Information System, Washington, D.C.

[5/] Within a functional economic area, commuters represent a relatively small proportion of the work force (Berry 1966).

Table 2—Comparison of the various components of export base industries of 4 Montana and Oregon communities, 1970[1/]

Export base industry	Missoula (Montana)		Flathead (Montana)		Linn-Benton (Oregon)		Douglas (Oregon)	
	Earnings	Percentage of total export base earnings	Earnings	Percentage of total export base earnings	Earnings	Percentage of total export base earnings	Earnings	Percentage of total export base earnings
	Million 1972 dollars		Million 1972 dollars		Million 1972 dollars		Million 1972 dollars	
Agriculture	1.7	2.2	3.3	6.5	19.9	10.4	.8	.7
Other manufacturing	.7	.9	.9	1.8	6.3	3.3	7.0	6.6
Mining and other export industries	.5	.6	.7	1.4	21.7	11.4	1.5	1.4
Primary metals refining	2/	2/	10.9	21.4	2/	2/	2/	2/
Wood products	27.0	35.0	20.0	39.2	77.2	40.5	79.3	74.3
Food processing	--	--	--	--	7.8	4.1	.7	.7
Higher education	15.9	20.6	--	--	39.5	20.9	--	--
Wholesale trade	3.0	3.9	--	--	--	--	--	--
Retail trade	4.4	5.7	1.3	2.5	--	--	--	--
Transportation	8.0	10.4	6.0	11.8	2.0	1.0	1.9	1.8
Lodging	1.2	1.6	1.1	2.2	.8	.4	1.1	1.0
Federal Government	14.6	18.9	6.9	13.5	15.2	8.0	14.6	13.7
Total 3/	77.1	100.0	51.0	100.0	190.5	100.0	106.8	100.0

1/ Earnings in 1972 dollars consist of wages and salaries, proprietors' income, and other labor income (mostly monetary fringe benefits).

2/ To avoid disclosing data for individual firms, "Primary metals refining" is combined with "Mining and other export industries."

3/ Totals may be off because of rounding.

Source: U.S. Bureau of Economic Analysis, Regional Economic Information, Washington, D.C., 1980; Montana Employment Security Commission, 1980; Helena, Montana, unpublished data, 1980; Oregon Employment Division, Salem, Oregon, unpublished data, 1980.

We analyze the export industries in terms of earnings rather than employment, because earnings affect the local economy. The components (as of 1970) of the export base in the four communities are compared in table 2.[6/] The wood products industry is the largest component of the economic base in each community. Even so, there is considerable variation among communities. The Douglas community, where the wood products industry accounted for the largest percentage of the economic base, is most dependent on timber. Linn-Benton is a distant second, and the Flathead and Missoula communities are third and fourth.

Export Base of the Four Timber-Dependent Communities

The earnings data for the wood products industry understate the importance of the forestry resource sector because they include only the private wood products workers—the loggers and the sawmill, plywood, and paper plant workers. Excluded are State and Federal government employees who manage a variety of forest and related resources on public lands. In Missoula there are several USDA Forest Service offices, the headquarters of the Montana Division of Forestry, and other government agencies related to forestry. These Missoula-based agencies had a combined total of about 1,100 employees, with estimated earnings of about $16 million. Adding this figure to that of the private wood products industry suggests that forest resources accounted for slightly more than 50 percent of Missoula's export base in 1970. Likewise, forest resources accounted for about 50 percent of the 1970 export base for both the Flathead and Linn-Benton communities. In the Douglas community, the addition of government employees concerned with forest land management boosted the importance of forest resources to well over 80 percent of the export base.

6/ The export base industries are listed in the appendix tables. We used the Standard Industrial Classification (SIC) Manual (Office of Management and Budget 1972) as a guide.

n addition to their dependency on timber, he four communities had other economic similarities. Higher education accounted or about 20 percent of the 1970 export ase of both Missoula and Linn-Benton. Data for the University of Montana in Missoula and Oregon State University in Corvallis provide a good example of the advantages of analyzing the export base ndustries by earnings instead of employment. In 1970, the 3,000 employees of he University of Montana represented bout 30 percent of the total export base employment, but only 21 percent of the asic earnings. The employment figures nay overstate the importance of the niversities because many jobs may be illed by students working only a few ours a week.

Missoula, in particular, and Flathead, to a esser extent, are trade centers. For Missoula, a portion of the earnings and employment in both wholesale and retail rade is dependent on the spending of onresidents, and this portion is included the export base (Polzin 1977). Although hey are often grouped together, the xport components of wholesale and etail trade are different. In Missoula, the xport component of retail trade repreents the persons who come to shop, ncluding those living on farms and anches or in nearby towns; the tourists who stop and buy items or purchase meals from the local businesses; and the onlocal students at the University of lontana. With the exception of nonresident students, the same holds for the lathead area. The export component of holesale trade, on the other hand, cludes the Missoula wholesalers who upply retail stores elsewhere in western lontana.

he transportation industry is a minor mponent of both Oregon communities. the Missoula and Flathead comunities, however, this industry—mainly ilroad jobs—accounts for a significant rtion of the economic base.

Primary metals refining is a major contributor to the export base in both the Flathead and Linn-Benton communities. In fact, the Anaconda Company's aluminum refinery near Columbia Falls, Montana, accounted for about 21.3 percent of total export earnings and was the second largest component of the export base in the Flathead community. In the Linn-Benton community, primary metals refining was included in the "Other manufacturing" category to comply with State reporting requirements (to avoid disclosure of an individual firm's activity). The major facilities are the zirconium and titanium refining installations near Albany. Agriculture was relatively unimportant in the four communities. Only in Linn-Benton did it account for more than 10 percent of the economic base.

Structural differences among the communities are related to the way economic stimuli are transmitted from one sector to another. Table 3 presents export base ratios for the four communities. These ratios represent the importance of the basic industries to the total economy and may reflect the size of the multiplier (the larger the ratio the greater the multiplier). Notice that the export base ratios for the two Montana communities were larger than those for the Oregon communities. This is somewhat surprising because the Flathead and Missoula communities had smaller populations than did Linn-Benton and Douglas, and the multiplier is usually thought to be correlated with population (Tiebout 1962). The remoteness of communities in the Rocky Mountain region may account for this anomaly. As Polzin points out:[2/]

> Because of the small size of the towns and the dispersed population, regional trade and service centers of only modest size may have a market area extending for hundreds of miles and may include ten, twenty, or even more counties. For example, Billings, Montana, with a population slightly less than 100,000 persons, has a primary trade area considerably larger than the state of Pennsylvania.

2/ Polzin, Paul E. How to win friends and sleep at night while using economic base analysis. Paper presented at the 18th Annual Meeting of the Western Regional Science Association, Monterey, Calif. Feb. 1980.

Table 3—Export base ratios for 4 Montana and Oregon timber-dependent communites, 1970[1/]

Communities	Ratios
Montana:	
Flathead	1.93
Missoula	2.19
Oregon:	
Linn-Benton	1.77
Douglas	1.86

1/ Derived as follows:

$$\text{Base ratios} = \frac{\text{total earnings, 1970}}{\text{basic earnings, 1970}}.$$

Despite their smaller populations, the two Montana communities are regional trade centers and may be higher on the regional hierarchy of cities than the Oregon communities. This suggests that local residents have less of a tendency to shop elsewhere, and therefore their propensity to spend locally may be greater. The result may be larger multipliers. If this is the case, equal increases in export earnings have a greater impact in the Missoula and Flathead communities than in the Linn-Benton and Douglas communities.

The retirement industry is absent from our compilation of export base components. Retirement earnings (included in the transfer payments category) are a rapidly growing source of income for the four study communities. Some analysts include transfer payments as part of the export base, but we discuss them in a separate section.

In summary, there were significant differences among the four communities in the structure of their export base industries. Douglas was by far the most dependent on timber, with over 80 percent of its export base directly or indirectly associated with wood products. Wood products were a major, but not a dominant, component in the other communities, accounting for roughly 40 to 60 percent of the export base. Other industries, such as higher education and primary metals refining, also played a major role in these communities.

To gain a long-term perspective, we will examine prospects for growth of the four communities, as perceived by various authorities about 1970. We will examine the outlook for the wood products industry first; then we will consider likely developments in other basic industries.

Prospects for the Timber-Dependent Industries

For all practical purposes, the sawtimber supply in western Montana was being totally used in 1970. A USDA Forest Service (1959) report suggested that some reduction in sawmill capacity was appropriate. The outlook, nevertheless, was for modest increases in employment for the wood-using industries. Employment growth was expected to be much less than in the 1960's and to be in the processing of wood fiber residues (pulp and paper, particle board, and fiberboard) rather than sawtimber (Nelson 1963, Polzin 1972); that is, growth in the wood products industry was expected to result from increased utilization of the existing harvest, rather than increases in the level of harvest. Such a change would alter the relationship between timber harvesting and employment and earnings.

In contrast to the situation in western Montana, prospects for growth in the wood products industry in western Oregon were not encouraging in 1970. Log production from public lands had more than doubled between 1950 and the mid-1960's, but private harvest, which had accounted for the bulk of log production, had begun to stabilize (Brodie and others 1978). As a consequence, total timber harvest also showed signs of leveling off. Furthermore, a comprehensive analysis of public and private timber supply in the Douglas-fir region disclosed that, barring major changes in timber management policies, total timber output from all lands in western Oregon would soon decline (USDA Forest Service 1969).[8/] These findings more or less conformed with Hamill's (1963) prediction of a shortfall in total log supply in the Douglas community. Because decisions of private forest-land owners could not be anticipated, however, the timing of the shortfall was difficult to predict.

The wood products industry in western Oregon was already using a high proportion of mill residues. Furthermore, reduction in the proportion of timber harvests left as logging residue was not expected to significantly affect total removal (USDA Forest Service 1973). The wood products industry in western Oregon, unlike in western Montana, was not likely to profit from increased utilization.

In summary, prospects for growth of the timber industry did not appear as favorable for Oregon as for western Montana. Although a downturn in timber supply did not appear imminent, prospects for increases for Oregon appeared unlikely. Installed sawmill capacity probably exceeded sawtimber supply in Montana, but increased activity based on the more intense utilization of the available timber supplies appeared likely.

Prospects for the Nontimber Export Base Industries

Prognostications, circa 1970, regarding the timber industry focused mainly on the supply of sawtimber and the further utilization of residues. But for several of the base industries not dependent on timber, market factors, as well as supply factors, were important considerations. For example, the future trends in the world aluminum market were thought to be the most important determinant of employment and earnings at the refinery in the Flathead community. But there were no announced plans to increase employment or output at the Anaconda Company's facility at Columbia Falls, Montana (Bonneville Power Administration 1970), even though employment in the aluminum industry throughout the Pacific Northwest was expected to double between 1965 and 1980.

Although aluminum refining in the Flathead community was not expected to provide an immediate impetus for economic growth, processing of exotic metals was just commencing in the Linn-Benton community. Nationwide, titanium consumption was expected to grow rapidly because of increased use in the fabrication of jet engines, missiles, spacecraft, and commercial aircraft. In the Linn-Benton community, direct employment in this industry was projected to increase from 300 employees in 1970 to 1,200 in 1980 (Bonneville Power Administration 1970). In addition, Albany (in the Linn-Benton community) became the site of the Nation's only zirconium refinery. Nuclear electric plants are powered by zirconium-sheathed fuel rods. Though specific forecasts were not available, anticipated growth of the nuclear power industry was expected to require increased production of zirconium.

The University of Montana and Oregon State University, like other centers of higher education, seemed destined to contribute significantly to the economic growth and development in the Missoula and Linn-Benton communities. Enrollments at both institutions grew rapidly during the late 1960's. There was, however, some concern that the future economic stimuli generated by these institutions during the 1970's might not be as great as it was during the 1960's (Polzin 1972). These forecasts were based on the possibility of enrollment ceilings and the ending of the military draft. The demographic influences on enrollment were not fully recognized at this time. Although neither institution had attracted "think tanks" nor computer (based) and electronic industries like their counterparts in California and the eastern seaboard had, some authorities believed they would eventually.

[8/] The timber supply situations described in the Douglas-fir supply study report (USDA Forest Service 1969) differed significantly from the outlook described in the so-called Bonneville report (Gedney and others 1966). The latter predicted the cut in the Pacific Northwest (Idaho, western Montana, Oregon, and Washington) to increase 28 percent by 2010. This included an increase of 23 percent for western Oregon and western Washington.

Increases in Federal civilian employment were expected to be a major contributor to economic growth in Missoula and Flathead (University of Montana 1970). Expanding Federal payrolls were expected to result from new Federal programs oriented to social and human resources and growth in existing programs. In the Douglas community, Federal employment increased considerably during the 1960's—mainly as a result of forest management activities—but future growth was questionable (Gudger and Smith 1972). In the absence of new programs, Federal employment would depend mostly on the timber industry. In the Linn-Benton community, Federal Government activities were more varied (for example, Federal Water Pollution Control Administration—now Environmental Protection Agency—and the Bureau of Mines), and future trends were not thought to be as dependent on the timber industry.

In addition to affecting the multiplier, the trade center functions of Missoula and Flathead were expected to contribute directly to growth in the economic base. Throughout the postwar period, retail trade was increasingly concentrated in regional trade centers; people in the hinterland spent more of their incomes in trade centers, leading to the demise of some small towns as retail centers. This trend was likely to continue during the 1970's. But the future growth of the Missoula and Flathead communities as trade centers was uncertain because the market area of both was bounded by even larger trade centers to the west (Spokane) and the east (Great Falls and Billings).

The contribution of the trade centers to the economic base in the Missoula and Flathead communities was recognized in the early 1970's (Polzin 1972). But future growth in these centers did not appear promising because slow economic growth was projected for the rural areas served by the Missoula and Flathead merchants.

Decreased passenger rail service and the abandonment of branch lines led to sharp declines in railroad employment during the 1960's. These trends were expected to continue into the 1970's, albeit at a slower rate, and to reduce the importance of railroads to the economies of the Missoula and Flathead communities (University of Montana 1970).

In the early 1970's, tourism was recognized as a potential contributor to economic growth in western Montana (Polzin 1972). This industry was not extensively analyzed because of the lack of data. But certain negative features, such as seasonality and low wages, were recognized. Nevertheless, the Missoula and Flathead communities, because of their proximity to national parks and wilderness areas, appeared well situated to benefit from growth in outdoor recreation. Although Oregon's outdoor recreation industry was expected to grow, the impact on the Linn-Benton community would be mainly indirect because most activity would occur elsewhere (Farness and Sitton 1968). Outdoor recreation was being touted as a potential growth industry in the Douglas community (Gudger and Smith 1972), but any growth would require a well-planned promotion.

In the Linn-Benton community, agriculture and food processing were the only resource-based industries likely to exhibit significant growth during the 1970's (Farness and Sitton 1968). Agriculture was a minor component of the export base in the other three communities.

In summary, the Montana communities experienced rapid growth during the 1960's (tables 4 and 5). In contrast, the Oregon communities exhibited modest growth (tables 6 and 7). In fact, population growth in the Douglas community showed signs of weakening.[9/] In 1970, the outlook for the four communities was not rosy. The prospects for the wood products industry were not promising, although they seemed better in the Montana communities because of the possibility of increased utilization of the timber resources. The bright spots in the Missoula and Linn-Benton communities were the universities, and in the Linn-Benton community the demand for primary metals appeared strong.

9/ Though total population continued to grow between 1960 and 1970, there was a decrease in net migration (inmigration minus outmigration) of 5,450 persons in the Douglas community during this period (Gudger and Smith 1972).

Table 4—Summary of economic outlook for selected components of the export base of the Missoula community, Montana, 1970

Basic industry	Experience during the 1960's	Implication for future growth
Wood products	Rapid expansion in output, employment, and labor earnings	Continued growth in employment, but more moderate than during the 1960's; sawtimber supply limited; increased employment associated with further processing of harvest
University of Montana	Rapid increases beginning in the mid-1960's	Modest growth, but full implication of changing demographics not understood
Export component of wholesale and retail trade	Not explicitly analyzed because of lack of data	Small increases because of slow growth in the trade area
Transportation	Significant decreases in railroad employment	Continued decline in railroad employment
Tourism	Not explicitly analyzed because of lack of data	Growth; but it will have only limited impact on total economy because jobs have low wages and are seasonal
Federal Government	Rapid increases in employment and earnings	Continued growth, but at slightly slower rate than during the 1960's
Retirement payments	Not assessed	Not assessed
Economy in general	Rapid growtn in population, employment, and earnings	Continued growth, but at slower rate than during the 1960's

Table 5—Summary of economic outlook for selected components of the export base of the Flathead community, Montana, 1970

Basic industry	Experience during the 1960's	Implication for future growth
Wood products	Rapid expansion in output, employment, and labor earnings	Continued growth in employment, but more moderate than during the 1960's; sawtimber supply limited; increased employment associated with further processing of harvest
Aluminum refining	Not explicitly analyzed	Trends in employment and earnings will depend on worldwide developments in this industry
Export component of wholesale and retail trade	Not explicitly analyzed because of lack of data	Small increases because of slow growth in trade
Transportation	Significant decreases in railroad employment	Continued decline in railroad employment
Tourism	Not explicitly analyzed because of lack of data	Growth; but it will have only limited impact on total economy because jobs have low wages and are seasonal
Federal Government	Rapid increases in employment and earnings	Continued growth, but at slightly slower rate than during the 1960's
Retirement payments	Not assessed	Not assessed
Economy in general	Rapid growth in population, employment, and earnings	Continued growth, but at slower rate than during the 1960's

Table 6—Summary of economic outlook for selected components of the export base of the Linn-Benton community, Oregon, 1970

Basic industry	Experience during the 1960's	Implication for future growth
Wood products	Major contributor to community's economy	Processing operations expected to continue at current levels, but because of sustained yield policies, expansion is unlikely
Oregon State University	Rapid growth in enrollment	Graduate and undergraduate programs are expected to continue growing
Primary metals	A growing contributor to the economy of the community	Could experience substantial growth because of increasing demands for nuclear reactor fuel rods (zirconium) and growth of the aerospace industry (titanium)
Computer and electronic	No activity	Growth prospects good because of proximity to Oregon State University
Trade	Not an export base activity	Continued reliance on Portland, Salem, and Eugene for high order goods and services
Retirement	Not assessed	Not assessed
Economy in general	Steady, but modest growth	Timber supply constraints will hinder growth of the wood processing sector, but continued growth of higher education, primary metals, and the prospects for attracting computer and electronic firms will more than balance the poor growth prospects of the timber industry

Table 7—Summary of economic outlook for selected components of the export base of the Douglas community, Oregon, 1970

Basic industry	Experience during the 1960's	Implication for future growth
Wood products	Dominant component of export base; growth continued, but at slower rate	Forecasted imminent shortfall in timber supply could lead to substantial reduction in timber processing activity
Mining	Nickel mining employment static	No prospects for significant growth
Federal Government	Rapid growth related to stepped-up public timber harvesting activity	Future growth questionable because high proportion of Federal Government employment depends on public timber harvesting activities
Retirement	Not assessed	Not assessed
Economy in general	Economy exhibited signs of weakening; for example, outmigration exceeded inmigration by substantial margin	Diversification could counteract decline of the timber industry, but prospects for such change difficult to assess

Economic Growth During the 1970's

Between 1970 and 1978, economic growth of the two Oregon communities differed little from that of the Montana communities. We discuss population, nonfarm earnings, and per capita income because they are general indicators of economic growth. We also discuss trends in specific export industries.

Table 8 presents 1970 and 1978 population and migration data for the four communities and, for perspective, the corresponding figures for Oregon and Montana. Of the four communities, Flathead had the greatest rate of population growth (26.7 percent), whereas Missoula had the lowest (19.6 percent). The growth rates for the Linn-Benton and Douglas communities were about equal (22.9 and 24.2 percent, respectively). The population growth rates in all four timber-dependent communities, however, exceeded their respective statewide averages.

Migration was the major source of population growth in all four communities (table 8). New migrants accounted for nearly 78 percent of the population increase in the Flathead community and for about 66 percent in the Douglas community. Though less impressive, migration displays similar trends in Missoula and Linn-Benton. Statewide, new migrants accounted for a much greater share of the population growth in Oregon than in Montana. Therefore, in the Linn-Benton and Douglas communities, new migrants accounted for a smaller proportion of the population growth than in the State. In Montana, the opposite occurred—migrants to the Flathead and Missoula communities represented a greater proportion of the population change than for the State as a whole.

Table 8—Resident population and migration in 4 communities in Montana and Oregon, 1970 and 1978

Community	Population		Change, 1970-78	Net migration,[2] 1970-78	
	1970	1978[1]			
	---Number of people----		Percent	Number of people	Percent[3]
Montana:	694,409	785,000	13.0	44,000	48.6
Flathead	39,460	50,000	26.7	8,200	77.8
Missoula	58,263	69,700	19.6	6,500	56.8
Oregon:	2,091,533	2,444,000	16.9	241,000	68.4
Linn-Benton	125,495	154,200	22.9	17,100	59.6
Douglas	71,743	89,100	24.2	11,600	66.8

[1] Provisional.

[2] Inmigration minus outmigration.

[3] Of 1970-78 change in population.

Source: U.S. Bureau of the Census, Current Population Reports, Series P-26, No. 78-76, Washington, D.C., 1979, table 1.

The trend in nonfarm earnings is probably the most reliable single index of local economic growth because of the high correlation between economic activity and the labor required to produce it. Nonfarm earnings is a sensitive index of economic activity because it takes into account differences in high- and low-paying jobs and may reflect changes in production not shown in the number of employees (such as a cutback in working hours or the scheduling of overtime). These figures must be interpreted carefully, however. For example, the growth rate of nonfarm earnings may overstate the actual increases in total economic activity in the local economy because wages may increase faster than production.

As can be seen in table 9, the rates of change for nonfarm earnings between 1970 and 1978 in the four communities differed by less than 10 percentage points, from a high of 68.6 percent in Flathead to a low of 59.7 percent in Douglas. The Douglas community, the most timber dependent of the four communities, exhibited the least growth in nonfarm earnings. The growth rates of all the communities exceeded the averages of their States.

Table 9—Nonfarm earnings in 4 communities in Montana and Oregon, 1970 and 1978

Community	1970	1978	Change, 1970-78
	- - Thousand 1972 dollars- -		Percent
Montana:	1,692,000	2,492,000	47.3
Flathead	95,591	161,189	68.6
Missoula	167,239	273,903	63.8
Oregon:	6,430,461	9,951,677	54.8
Linn-Benton	315,775	525,405	66.4
Douglas	201,005	320,920	59.7

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Information System, Washington, D.C., 1980; percentages derived.

Table 10—Per capita personal income in 4 communities in Montana and Oregon, 1970 and 1978[1/]

Community	Income		Change, 1970-78
	1970	1978	
	---1972 dollars---		Percent
Montana:	3,784	4,610	21.9
Flathead	3,439	4,604	33.9
Missoula	3,594	4,816	34.0
Oregon:	4,020	5,384	33.9
Linn-Benton	[2/]3,298	[2/]4,541	37.6
Douglas	3,464	4,675	34.9

[1/]Per capita income includes income from all sources.

[2/]Weighted average of Linn and Benton Counties.

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Information System, Washington, D.C., 1980; percentages derived.

Trends in per capita income for the Montana and Oregon communities are shown in table 10. Per capita income increased more for the Linn-Benton and Douglas communities than for the State of Oregon between 1970 and 1978. Per capita income in both the Missoula and the Flathead community increased more from 1970 to 1978 than did per capita income for the State of Montana.

Even though per capita income in each of the four communities grew faster than its respective State average, there were significant differences between the communities. In 1970, per capita income in Flathead and Missoula was roughly 5 to 10 percent below that of Montana. By 1978, per capita income in Flathead had risen to about the average for the State of Montana, whereas in Missoula it exceeded the average for the State by about 4.4 percent. In contrast, the Oregon communities began the decade with per capita income 14 to 18 percent below the State average and did not significantly improve their relative position by 1978. The trend in Montana, however, was due to relatively slow growth in per capita income, which increased 21.8 percent compared with 33.9 percent in Oregon, rather than by differences between the communities. Low agricultural incomes during 1978 in the eastern part of Montana were a major cause of relatively slow growth of income in the State.

Per capita income increased significantly in all four timber-dependent communities. This suggests that despite the crisis, the shortages, and the energy crunch, people were better off in terms of money income in 1978 than in 1970. The rise in per capita income may somewhat overstate an improvement; although the figures are corrected for inflation, they do not account for the increase in taxes to reveal disposable income after taxes.

Despite the similarities in growth trends, the Montana communities differ significantly from those in Oregon in their role in the regional economy. Specifically, Missoula and Flathead account for a relatively large share of the Montana economy. The Oregon communities, Linn-Benton and Douglas, although larger than their Montana counterparts in both population and nonfarm earnings, represent a smaller share of State totals.

The combined population and nonfarm earnings in the communities of Flathead and Missoula represent 15.3 and 17.5 percent of totals for Montana during 1978 (table 11). In contrast, the corresponding figures for the Linn-Benton and Douglas communities are 9.9 and 8.5 percent of the totals for Oregon. The relative importance of the Montana communities is also reflected in their roles as regional trade centers servicing adjacent areas. The Oregon communities, however, are served by the trade centers of Portland, Salem, and Eugene.

In summary, the general indicators of economic growth suggest that all four study areas may be classified as rapidly growing communities. All experienced positive net migration, and their growth rates for population, nonfarm earnings, and per capita income were greater than corresponding State averages. In addition, the growth rates for all the communities were usually within a few percentage points of each other.

Structural Differences and Economic Growth During the 1970's

The Missoula and Flathead communities are regional trade centers and, despite their smaller population, may provide a wider range of goods and services than do the Linn-Benton and Douglas communities. That is, the former rank higher in their respective regional hierarchy of cities. We speculated that the multiplier may be larger in the Montana communities. A comparison of growth in earnings in export industries with total nonfarm earnings tends to support these conclusions. As shown in table 12, the growth rates in total nonfarm earnings were similar in all four communities. But the increases in export earnings were much smaller in the Montana communities than in the Oregon communities.[10/]

Because of the importance of the Montana communities as trade centers, the performance of total nonfarm earnings relative to the change in the export industries is expected. But a close examination

Table 11—Population and nonfarm earnings of 4 communities in Montana and Oregon as a percentage of State totals, 1978

Community	Population	Nonfarm earnings
Montana:		
Flathead	6.4	6.5
Missoula	8.9	11.0
Total	15.3	17.5
Oregon:		
Linn-Benton	6.3	5.3
Douglas	3.6	3.2
Total	9.9	8.5

Table 12—Change in earnings of export industries and total nonfarm earnings between 1970 and 1978 for 4 communities in Montana and Oregon

Community	Export industries	Total nonfarm
	Percent	
Montana:		
Missoula	31.6	63.8
Flatnead	36.3	68.6
Oregon:		
Linn-Benton	48.0	66.4
Douglas	57.0	59.7

of specific export industries reveals some changes that might not have been anticipated in 1970. Perhaps the biggest surprise was the robust performance of the wood products industry. As shown below, earnings of wood products workers increased by more than 50 percent between 1970 and 1978 in three of the four communities:

Community	Change in total wood products earnings, 1970-78
	(Percent)
Missoula	73.8
Flathead	21.5
Linn-Benton	52.9
Douglas	57.0

Changes in the Timber Industry

Some of the increase in use of residues in the Montana communities could have been anticipated in 1970, but not the extent of the increase in Missoula.

Most growth of the timber industry in the Missoula community resulted from the construction of a new, large plywood mill in nearby Bonner. With the addition of this mill, Missoula became the State's largest wood-fiber processing center.[11/] In 1980, Missoula's pulp and paper mill completed a major expansion that significantly increases the total volume of wood fiber processed in the community.

The construction of the large plywood plant in Missoula illustrates one of the problems of analyzing small economies; namely, that the actions of a firm or individual may have a significant impact. In this case, the opportunity for expansion in the wood products industry was identified in the early 1970's. What could not be anticipated was the nature, size, and location of the new facility. This suggests that planners must be cautious about predicting economic development. They may correctly perceive the opportunities but not anticipate the actions of an individual or a firm.

In Oregon, earnings from the sale of wood products also rose, but this did not negate the relatively pessimistic timber supply outlook in 1970 because the accelerated harvesting during the 1970's probably came at the expense of the future.

The growth of the wood products industry must be put in perspective. Table 13 shows that the wood products industry was not equally important to the growth of each community. In Missoula and Douglas, increases in wood products earnings dominated the growth in the export industries; they accounted for almost 82 percent of the total growth in the economic base of the Missoula community and about 74 percent of Douglas. In the Linn-Benton community, the wood products industry represented about 45 percent of the total increase in export earnings and 23 percent in Flathead. The wood products industry was the major cause of growth in the basic industries in Missoula and Douglas, an important but not dominant factor in Linn-Benton, and a relatively minor contributor in Flathead.

10/ Agriculture is relatively insignificant in all four communities, and its inclusion in export earnings but not in total nonfarm earnings should not seriously bias the comparison.

11/ Keegan, Charles P., III. Forest industries data collection systems. Bureau of Business & Economic Research, University of Montana, Missoula, Mont. 1981.

Table 13—Change in earnings in export industries of 4 communities in Montana and Oregon, 1970-78[1]

Export industry	Missoula (Montana)		Flathead (Montana)		Linn-Benton (Oregon)		Douglas (Oregon)	
	Change, 1970-78	Percent of total change	Change, 1970-78	Percent of total change	Change, 1970-78	Percent of total change	Change, 1970-78	Percent of total change[2]
	Thousand dollars		Thousand dollars		Thousand dollars		Thousand dollars	
Agriculture	-1,196	-4.9	273	1.5	-3,513	-3.9	6,583	10.8
Mining and other export industries	192	.8	-25	-.1	24,503	27.0	2,245	3.7
Primary metals	0	0	9,502	51.2	0	0	0	0
Wood products	19,957	81.9	4,310	23.2	40,585	44.7	45,196	74.2
Food processing	0	0	0	0	1,989	2.2	-591	-1.0
Other manufacturing	647	2.6	-98	-.5	17,615	19.4	3,408	5.6
Higher education	-1,006	-4.1	0	0	3,306	3.6	0	0
Wholesale trade	-1,673	-6.9	0	0	0	0	0	0
Retail trade[2]	1,888	7.7	183	1.0	0	0	0	0
Transportation	480	2.0	876	4.7	1,202	1.3	-378	-.6
Lodging	655	2.7	1,707	9.2	829	.9	570	.9
Federal Government	4,429	18.2	1,839	9.9	4,285	4.7	3,915	6.4
Total[3]	24,373	100.0	18,567	100.0	90,801	100.0	60,948	100.0

[1] In 1972 dollars.

[2] Only a portion is in the export base.

[3] Totals may be off because of rounding.

Nontimber Sectors Continue To Expand

Primary metals refining and computer manufacturing (included in the "Other manufacturing" category) were the major contributors to growth in the Linn-Benton community. Primary metals also played a major role in the Flathead community. In Flathead, earnings in primary metals refining almost doubled between 1970 and 1978, and it was the largest single contributor to the growth of export base earnings in the Flathead community. This increase was due to the additional employment associated with converting the Anaconda Company's aluminum smelter in Columbia Falls to a new process that uses Japanese technology. The new process reduced energy needs by 28 percent and upgraded pollution control equipment (Marple and Parks 1978). Modifications were begun in 1977 and were completed in April 1980; therefore, the 1978 data may somewhat overstate the longrun importance of this industry to the local economy because it includes the earnings of some construction workers. In the Linn-Benton community, the major new activity was construction of the Hewlett-Packard assembly plant. This facility, combined with expansion in primary metals, accounted for about 46 percent of the total increase in export earnings. The increases in Linn-Benton, at least the portion associated with the expansion in primary metals refining, were anticipated in 1970. But the modifications at the Anaconda Company's aluminum smelter in Flathead, which did not significantly change production capacity, were not expected at the start of the decade.

Missoula and Flathead continued as regional trade centers, but this specialized role did not significantly contribute to growth in the economies of these communities during the 1970-78 period. In Missoula, the $1.9 million increase in the export component of retail trade was almost counterbalanced by the $1.7 million decline in the export component of wholesale trade. This did not mean that Missoula wholesalers were losing customers, but simply that a greater share of their sales could be attributed to expansion of local markets. The export component of retail trade in Flathead increased about $183,000 between 1970 and 1978 and represented less than 1 percent of the total growth in export industries.

Table 14—Comparison of the importance of various export industries (earnings basis) for Montana and Oregon communities, 1970 and 1978

Industry	Missoula (Montana)		Flathead (Montana)		Linn-Benton (Oregon)		Douglas (Oregon)	
	1970	1978	1970	1978	1970	1978	1970	1978
				Percent				
Agriculture	2.2	0.5	6.5	5.1	10.5	5.8	0.7	4.4
Mining and other export industries	.6	.7	1.4	1.0	11.4	16.4	1.4	1.3
Primary metals	0	0	21.3	29.3	0	0	0	0
Wood products	35.0	46.3	39.1	34.9	40.5	41.9	74.3	74.2
Food processing	0	0	0	0	4.1	3.4	.7	.1
Other manufacturing	.9	1.3	1.8	1.1	3.3	8.5	6.6	6.2
Higher education	20.6	14.7	0	0	20.7	15.2	0	0
Wholesale trade[1/]	3.9	1.3	0	0	0	0	0	0
Retail trade[1/]	5.7	6.2	2.5	2.1	0	0	0	0
Transportation[1/]	10.4	8.4	11.7	9.9	1.0	1.2	1.8	.9
Lodging	1.6	1.8	2.2	4.0	.4	.6	1.0	1.0
Federal Government	18.9	18.7	13.5	12.6	8.0	6.9	13.7	11.0
Total[2/]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1/] Only a portion is in the export base.

[2/] Totals may be off because of rounding.

Earnings of Federal employees contributed to the growth of the economy in all four communities. The increase in Federal earnings ranged from a low of 4.7 percent of export base industries in Linn-Benton to a high of 18.2 percent in Missoula. Because a sizable share of the Federal employees are concerned with managing public land, this suggests that the figures for the wood products industry understate the true contribution of forest resources to growth in the economies of these communities. The increase in Federal earnings were, for the most part, due to rising Federal pay scales, rather than to increases in the number of Federal workers. Contrary to the 1970 outlook, expansion of social and human resources programs did not lead to significant increases in Federal employment.

Higher education did not make a significant contribution to the growth in either the Missoula or the Linn-Benton community. In fact, earnings at the University of Montana actually declined about $1.0 million between 1970 and 1978. The corresponding figure for Oregon State University (OSU) was an increase of $3.3 million, representing about 3.6 percent of the total increase in the export industries in Linn-Benton. The figures for OSU may understate its contribution to total economic growth because Linn-Benton, unlike Missoula, has attracted some computer-based industries. It is difficult to classify the relatively slow growth of the universities as either anticipated or not anticipated in 1970. An astute demographer may have correctly observed in 1970 that much of the increase in the 1960's was due to aberrations caused by the postwar baby boom. On the other hand, in 1970 many observers still viewed higher education as a growth sector.

Table 14 presents the relative importance of the export base industries during 1970 and 1978 in each of the four communities and summarizes the effects of growth. In terms of timber dependency, the two Oregon communities changed little. The wood products industry still accounts for nearly 75 percent of Douglas's economic base; about 40 percent of Linn-Benton's. Timber dependency in the Montana communities went in opposite directions. Whereas Missoula is now more dependent on timber than it was at the start of the decade (46 percent in 1978 compared with 35 in 1970), the importance of the wood products industry to Flathead's economy has declined (35 vs. 39 percent). The latter was accompanied by an increase in primary metals refining. In summary, only Missoula experienced a significant change (10-percent increase) in timber dependency during the 1970's; in the other three communities, the relative importance of the wood products industry in 1978 was within 5 percent of the figure for 1970.

Retirement Income—A Growing Component of the Export Base

Retirement income and other forms of transfer payments (transfer payments include income received for which no current services are rendered) have been one of the fastest growing components of personal income in the United States (Renshaw and Friedenberg 1977). Further, Connaughton (1979) found that transfer payments were the fastest growing component of the export base sector in timber-dependent communities in northern California.[12/] Therefore, by looking only at the traditional export base industries, we may miss an important component of growth.

[12/] The net contribution of transfer payments to the export base is equal to payments received by local residents minus their contributions to Social Security.

The economic impact of retirees is difficult to determine because some key data on the sources of income for retired persons are missing. In addition, there are conceptual problems about the correct method for analyzing retirement payments so that they are comparable to the figures for export base industries. The available data are presented, however, in an attempt to shed some light on the economic role of the retirement community in the timber-dependent communities.

Tables 15 and 16 present retirement payments from selected sources to persons in the four timber-dependent communities and the States of Oregon and Montana. The first item reports Social Security and Medicare payments. The remaining sources include payments to retired Federal civilian workers, State and local government workers, and railroad workers and pensions to military personnel. Data are not available for payments from private pension funds and dividends, interest, and rents that retirees may receive from past investments.

Table 15 shows that total retirement payments from government sources to Flathead residents increased from about $15.5 million in 1970 to almost $28.0 million in 1978. Even after they were corrected for inflation, retirement payments from these sources increased about 80 percent. In Missoula, the payments rose from about $18.8 million in 1970 to about $33.9 million in 1978, or roughly 80 percent. Total payments to all Montanans from these sources increased 74.7 percent between 1970 and 1978.

Retirement payments to residents of the Oregon communities are shown in table 16. In Linn-Benton, total retirement payments increased about 97 percent—from $30.9 million in 1970 to $61.0 million in 1978. Total payments to Douglas residents rose from $20.9 million to about $40.7 million or 94.2 percent between 1970 and 1978. Statewide, payments from these sources to Oregon residents increased abut 85.4 percent between 1970 and 1978.

Table 15—Retirement and related transfer payments from selected sources, Flathead and Missoula communities and the State of Montana, 1970 and 1978

Retirement payments and related transfer payments	Flathead			Missoula			Montana		
	1970	1978	Change, 1970-78	1970	1978	Change, 1970-78	1970	1978	Change, 1970-78
	Thousand 1972 dollars		Percent	Thousand 1972 dollars		Percent	Thousand 1972 dollars		Percent
Social Security and Medicare	8,768	16,900	92.7	10,068	18,662	85.3	144,787	252,248	74.2
Federal civilian pensions	999	2,083	108.5	1,672	3,353	100.5	12,093	28,027	131.8
State and local pensions	569	1,401	146.2	1,320	2,946	123.2	13,809	30,517	121.0
Military pensions	2,351	3,395	44.4	2,595	3,524	35.8	29,384	40,015	36.1
Railroad pensions	2,842	4,174	46.8	3,136	5,378	71.5	13,661	22,585	65.3
All payments	15,529	27,953	80.0	18,791	33,863	80.2	213,734	373,392	74.7
Percent of personal income	11.4	12.1		8.9	10.1		8.1	10.3	

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Information System, Washington, D.C., 1980, unpublished data.

Table 16—Retirement and related transfer payments from selected sources, Linn-Benton and Douglas communities and the State of Oregon, 1970 and 1978

Retirement payments and related transfer payments	Linn-Benton			Douglas			Oregon		
	1970	1978	Change, 1970-78	1970	1978	Change, 1970-78	1970	1978	Change, 1970-78
	Tnousand 1972 dollars		Percent	Thousand 1972 dollars		Percent	Thousand 1972 dollars		Percent
Social Security and medicare	21,685	44,061	103.2	14,731	30,193	105.0	481.205	917,953	90.8
Federal civilian pensions	1,605	4,221	162.9	1,202	3,222	168.1	39,444	93,860	137.9
State and local pensions	1,701	3,749	120.3	677	1,632	141.1	24,440	54,272	122.1
Military pensions	5,684	8,438	48.5	3,964	4,974	25.4	105,150	144,327	37.3
Railroad pensions	265	485	83.0	362	642	77.3	22,067	36,172	63.9
All payments	30,940	60,954	97.0	20,936	40,663	94.2	672,306	1,246,584	85.4
Percent of personal income	7.4	8.9		8.4	9.8		8.0	9.5	

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Information System, Washington, D.C., 1980, unpublished data.

Diversification of the Export Base

Although none of the four communities are characterized as retirement communities, the increase in these selected retirement payments has been impressive. There are still conceptual and empirical issues about the correct treatment of transfer payments in a model of local economic change, and most analysts would not simply lump them with other basic earnings without making some adjustments. A rough measure of the changing role of retirement payments in the four communities may be derived by comparing their growth rate with that of total export earnings (table 17).

In each community, retirement payments rose at a much greater rate (almost double in several cases) than total export earnings between 1970 and 1978, showing the importance of retirement payments to the economic base of each community.

Table 17—Comparison of growth in selected retirement payments and export earnings for 4 communities in Montana and Oregon, 1970-78

Community	Selected retirement payments	Export earnings
	Percent	
Montana:		
Missoula	80.2	31.6
Flathead	80.0	36.3
Oregon:		
Linn-Benton	97.0	47.6
Douglas	94.2	57.1

Community stability and economic diversity are related. The more diverse a region's economic base, the less likely that events in one component will dominate the economic trends. We use the "entropy" measure (the larger the index, the higher the degree of diversification) to examine diversification trends of the four communities.[13/] Calculations of the entropy index for the four communities are presented in table 18. Two sets of figures are shown for each community; the first corresponds to a narrow view of the basic sector and includes only the export industries; the second incorporates the simplistic assumption that retirement payments are analogous to export earnings.

13/ Kort (1979) demonstrated that the entropy measure overcomes the shortcomings of traditional indexes of industrial diversification. He describes the entropy measure as follows:

Entropy in the context of industrial diversification may be defined as:

$$H^D = \sum_{i=1}^{N} \left(\frac{e_i}{e}\right) \ln \left(\frac{e_i}{e}\right),$$

where H^D, the entropy measure of industrial diversification for a particular region and time period, is equal to the negative summation of the product of the regional employment proportions in the N industries and the natural logarithm of these proportions; e_i is equal to the employment in the i^{th} industry in this particular region, and e is equal to total regional employment. The ratio e_i/e is thus the regional employment proportion of the i^{th} industry in this region.

Kort (1979) chose the entropy measure or diversification because:

(1) it is single-valued in its arguments; (2) it is size and scale independent; (3) it can be modified to consider either continuous or discrete distributions; (4) there is additivity in the case of independent events; and (5) it can measure two scales simultaneously; i.e., total entropy can be decomposed into between-set and within-set components.

As measured by the entropy index, the export base of the Montana communities was generally more diversified than that of the Oregon communities in 1970. With or without retirement payments, the 1970 entropy index was greater in Missoula and Flathead than in Douglas. Linn-Benton appeared somewhat more diversified than Flathead, but less than Missoula. The figures for this measure of diversification reflect our earlier observations concerning the structure of these communities—we identified Douglas as the most timber dependent, and it has the lowest entropy value (least diversified) of the four communities.

More important than the level of diversification is its trend during the 1970's. Without retirement payments, two of the four communities (Missoula and Flathead) had lower entropy values (less diversification) in 1978 than in 1970. Even with retirement payments, Flathead experienced declining entropy values from 1970 to 1978. Linn-Benton exhibited slightly more diversity in 1978 than in 1970. Douglas, the least diversified community, was the only one with significant increases in entropy values in both cases. But the increases and decreases in the index, with and without retirement payments, were relatively small for all four communities, suggesting little change in diversification.

Table 18—The entropy measure of the diversity of the export base industries of Montana and Oregon communities, without and with retirement payments, 1970 and 1978

Community	Without retirement payments			With retirement payments		
	1970	1978	Change, 1970-78	1970	1978	Change, 1970-78
Montana:						
Missoula	1.7600	1.5820	-0.1780	1.9120	2.0110	+0.0990
Flathead	1.6990	1.6710	-.0280	1.8670	1.8210	-.0460
Oregon:						
Linn-Benton	1.7496	1.7613	+.0117	1.9088	1.9173	+.0085
Douglas	.9190	.9528	+.0338	1.2106	1.2523	+.0417

Import Substitution and Longrun Growth

Import substitution occurs when local firms provide an increasing proportion of the goods and services purchased by residents. Import substitution is sometimes used as a strategy for promoting longrun economic growth. Because of their size, the four communities are unlikely to manufacture their own clothing or automobiles, but there may be some opportunities for import substitution in wholesale and retail trade. As the population increases, local merchants may improve the quality and expand the quantity of their goods to capture sales that were formerly provided by a nearby trade center. In wholesale trade, the distributors may decide to serve the expanding local market directly rather than from a regional center, as at Missoula and Flathead where trade represents a portion of the export base. The Oregon communities have not exhibited such tendencies. Furthermore, the Linn-Benton and Douglas communities are not likely to evolve into trade centers in the near future. Rather, they will continue to be served by the existing centers (Portland, Eugene, and Salem).

By themselves, the trends from 1970 to 1978 are revealing. They are even more significant when considered in light of some profound shifts in the timber supply situation and the changing composition of the export base sectors of the four communities.

Western Oregon

We now have a better understanding of Oregon's future timber supply than we did in 1970. At the beginning of the decade there was still reason to believe that timber harvest levels could be maintained, if not increased, in western Oregon. But two timber supply studies (Gedney and others 1975, Beuter and others 1976) demonstrated that the current level of harvesting from public lands will not be able to compensate for a sharp decline in timber harvest from private forest ownerships.

Beuter and others (1976) state that for the Douglas community "the current total timbershed harvest can be maintained through 1995, after which a decline of about 20 percent would occur if current policies and actions are pursued." Because the boundary of Linn-Benton community does not coincide with the timbersheds in the Beuter analysis, its future timber supply situation is a little more difficult to assess. Linn-Benton, in fact, straddles the "north coast" and the "mid-Willamette" timbersheds. According to Beuter and others (1976), the north coast area will have no difficulty maintaining current output despite the decrease in output from industrial ownerships. The mid-Willamette area, however, should experience a 25-percent drop in timber output before the turn of the century.

The proximity of Linn-Benton to the Lane County timbershed complicates the picture. In the latter area, timber harvest is expected to drop about 40 percent between 1975 and 2005. Depending on their competitive strength, Lane County timber producers could increasingly seek more timber outside the county. That is, Lane County shortages could adversely impact timber processors in the Linn-Benton community. On the other hand, the Linn-Benton timber industry may benefit from the expected increase in timber production from the north coast area of Oregon.

The shortfall in timber production from forest lands in western Oregon is not inevitable. If the nondeclining even-flow constraint for public lands were relaxed, the projected harvest decline could be significantly mitigated. For example, in the Douglas community it is possible for harvest from public lands to be increased immediately by as much as 20 percent without ever dropping below the longrun sustainable harvest level of the forest (Beuter and others 1976).

Western Montana

A comprehensive timber supply analysis is not available for Montana, so available data should be interpreted with caution. In 1978, the timber supply situation in Montana was similar to that of 1970. Softwood sawtimber growth per acre for all ownerships barely exceeded removals—97.4 vs. 91.1 board feet—whereas growth of softwood growing stock was double that of removals — 33.0 vs. 16.4 cubic feet per acre.[14/] This relationship reflects the fact that commercial forest land in Montana still supports a surplus of smaller size and probably less desirable species (Schweitzer and others 1975). But timber statistics for the State may not provide a true indication of the future timber supply of western Montana. High roadbuilding and logging costs, for instance, will continue to impede timber harvesting on National Forests. Furthermore, closer inspection of spatial and ownership harvesting activity reveals potential problems. For example, although sawtimber removals from National Forests were only 69 percent of sawtimber growth in 1977, harvests from National Forests have been declining since the late 1960's (fig. 3). This trend can be attributed to "changes in the classification of forest land and because manpower and budgets have not been adequate to cover the special planning, sales administration, and control required" (Schweitzer and others 1975). Meanwhile, the harvest of privately owned roundwood products has been increasing. Without this increase, the shortfall in total timber production in Montana would have been greater.

In terms of timber supply, the Flathead community is more self sufficient than Missoula. For example, in 1976 the Flathead community obtained only about 30 percent of its sawtimber from outside Flathead County. The Missoula community, on the other hand, imported nearly 70 percent of its sawtimber from other counties, including a substantial proportion from Flathead's "backyard" (Flathead, Lincoln, and Sanders Counties). Furthermore, 75 percent of the sawtimber received by mills in the Missoula community comes from privately owned lands. Mills in Flathead obtained only 30 percent of their sawtimber from private sources.

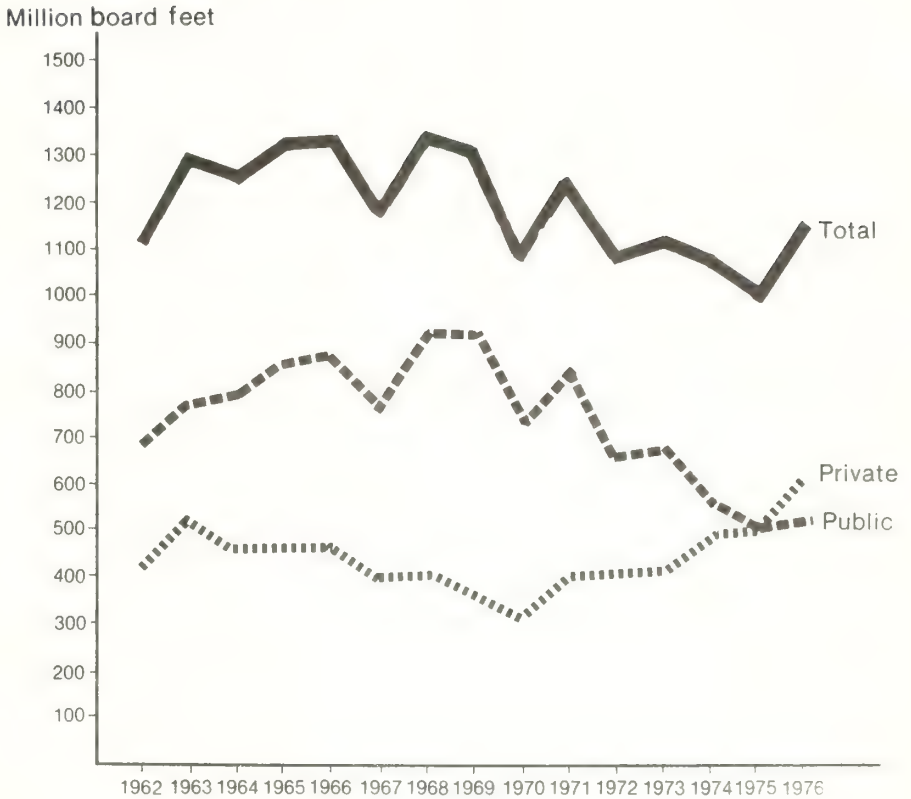


Figure 3.—Roundwood products harvested from Montana timberlands, by ownership, 1962-76 (adapted from Keegan 1980).

Timber Supply Prospects—A Summary

If there are no changes in public and private timber management policy, much of western Oregon can expect a shortfall before the turn of the century. The Douglas community is certain to be affected by any decline in timber supplies. But this shortfall could be circumvented by a departure from the nondeclining even-flow policy.

We lack a comprehensive projection of the future timber supply for Montana. Total output has been trending downward but few are expecting a shortfall similar to that forecasted for sections of western Oregon. Reduction of transportation costs could increase the harvest of nonsaw-log material (Schweitzer and others 1975) and, consequently, enhance the timber supply situation. But in the immediate future, the rate of decline would seemingly depend mainly on the ability of private forest-land owners to maintain current harvesting rates—that is, three times the current growth (see footnote 14). Although recommended harvest levels from the National Forests could eventually help reverse the downward trend, any appreciable increase in public timber offerings in western Montana will probably not come until after the year 2000 (USDA Forest Service 1980).

14/ Stone, Robert N. Measures of forest ownership performance timber production and harvest. Forest Products Laboratory, USDA Forest Service, Madison, Wis. 1980.

The following section reviews important changes during the 1970's and their implications for the future growth of each community. Tables 19, 20, 21, and 22 summarize these discussions.

Effects of Retirement

Extraordinary growth in retirement income was common to the four communities. This performance may not be repeated. Attempts to modify the Social Security System, for example, could result in advancing the age of retirement and reducing cost-of-living adjustments. Nevertheless, retirement income could cushion any instability resulting from timber shortages.

Diversity a Key Factor in the Missoula Community

In 1970, Missoula was least timber dependent of the four communities; yet the wood products sector accounted for most (82 percent) of the growth in Missoula's export base between 1970 and 1978. We anticipated that increased utilization of logging and mill residues would lead to some growth in the wood products industry, but the extent of this growth was surprising. As a result, the Missoula community was more dependent on timber in 1978 than it was in 1970.

The ability of the timber industry to maintain a high level of production may be more closely tied to changes in timber harvest levels because there can be no

Table 19—Summary of selected industry trends and their implications for future growth of the Missoula community, Montana

Basic industry	Experience during the 1970's	Implications for future growth
Wood products	Extent of growth unexpected	Continued growth depends on raw material supply
University of Montana	Slight decline caused by demographic trends and fiscal constraints	Unlikely source of future growth, but because of size will cushion any adverse economic trends
Trade	Maintained trade center function but did not experience significant growth	Could grow if oil and gas development in western Montana increases; most likely will remain a relatively small component of economic base
Transportation and tourism	Some growtn, but industry is not a significant component of economic base	A minor component of export base; furthermore, continued growth of tourism dependent on energy prices
Government	Grew principally as a result of pay increases	May buffer economy but no significant growth expected
Retirement	Grew faster than other components	May be constrained by political philosophy; retirement income will cushion any adverse trends
Economy in general	Exhibited significant deviations from expectations	Wood products industry could experience continued growth at expense of outlying communities; overall growth of economy appears certain

Table 20—Summary of selected industry trends and their implications for future growth of the Flathead community, Montana

Basic industry	Experience during the 1970's	Implications for future growth
Wood products	Modest growth	Future growth depends on raw material supply; unlike in the past, Flathead may have to compete with Missoula for local public timber
Primary metals	Substantial growth	Unlikely to expand because of energy constraints; may cushion instability in wood products industry
Trade	No marked change	Must compete with Missoula as trade center
Mining	No activity	Oil and gas development in Montana a possibility
Government	Grew principally as a result of pay increases	Administration of mineral development on public lands could result in modest increase; may cushion instability in wood products industry
Tourism	Significant growth	A minor component of export base; continued growth dependent on energy prices
Retirement	Grew faster than other components	May be constrained by political philosophy; some small retirement communities could materialize; retirement income will cushion adverse economic trends
Economy in general	Experienced significant growth as result of a primary metals refining industry and, to a lesser degree, the wood products industry	Growth will likely depend on performance of wood products industry

significant increases in the utilization of mill residues—most residues from sawmills and plywood plants are already used by the pulp, paper, and fiberboard mills. The future supply of timber depends on the status of removals from privately owned lands. If current levels cannot be maintained, wood processing plants in the Missoula community will have to rely more heavily on publicly owned timber. This may mean competing for public timber quite distant from Missoula. Missoula's timber industry could conceivably grow at the expense of timber producers elsewhere in western Montana (for example, the Flathead community). Some of Montana's larger, more modern and efficient wood-processing facilities are located in the Missoula community. Furthermore, Missoula's pulpmill offers a close, convenient outlet for mill residues. Missoula mills would, however, face higher raw material transportation costs if they must compete for public stumpage in outlying areas.

Table 21—Summary of selected industry trends and their implications for future growth of the Linn-Benton community, Oregon

Basic industry	Experience during the 1970's	Implications for future growth
Wood products	Grew at anticipated rate; was a major contributor to growth	Shortfall in private timber supply imminent; performance of local processors dependent on their ability to compete with mills in nearby counties for public timber
Oregon State University	Modest growth	Will help cushion the impact of any instability in the timber industry but not expected to contribute significantly to economic growth
Computer-based and electronic	Some growth but not a major contributor to growth	Future growth expected; could counteract any instability in the timber industry
Other manufacturing	Primary metals refining a major contributor to growth	Zirconium production will remain constant, but titanium production expected to increase
Retirement	Grew faster than other components	May be constrained by political philosophy, but retirement income will cushion the impact of any instability in the timber industry
Economy in general	Grew rapidly	Any decline in timber industry likely to be counterbalanced by increases in primary metals production and electronic computer-based industry

Table 22—Summary of selected industry trends and their implications for future growth of the Douglas community, Oregon

Basic industry	Experience during the 1970's	Implications for future growth
Wood products	Accounted for most of the growth	Raw material supply critical to growth
Mining	Increased, but not a significant contributor to growth	Uncertain
Government	Growth closely linked to forest-land management	No growth anticipated
Retirement	Grew faster than other components	May be constrained by political philosophy, but retirement income will help cushion the impact of any instability in the timber industry
Economy in general	Grew because of wood products industry	Little indication of diversification; consequently, public forest-land management policies crucial for growth in the immediate future

Besides wood products, the only other basic sector to experience significant growth between 1970 and 1978 was the Federal Government. This increase was mostly due to rising pay scales rather than more employees. Significant growth of this sector is unlikely in the near future. But, because it has been relatively stable, Federal employment could help cushion impacts resulting from a decrease in timber production in western Montana.

The University of Montana experienced a slight decline between 1970 and 1978 because of demographic trends and fiscal constraints. These trends will probably persist, so the University of Montana is not likely to be a source of growth in the future. Because it is the second largest component of the export base and declines will be small and predictable, the university may cushion any instability in the wood products industry.

Missoula continued to serve as a trade center, but this sector was not a significant source of growth during the 1970-78 period. Because this component plays a minor role, wholesale and retail trade are unlikely to contribute significantly to the future growth of the Missoula community's export base.

Missoula is near the "Overthrust Belt," a geological formation thought to contain recoverable crude oil and natural gas resources. Rising prices stimulated leasing of gas and oil in this community. Recent estimates indicate that development of gas and oil fields in western Montana is a strong possibility. Estimates of economically available, but as yet undiscovered, natural gas range from a low of 1.8 trillion cubic feet to a high of 20.6.[15] Though these reserves are modest compared with the estimated 249.1 trillion-cubic-foot reserve (high) of the Gulf States region, development of gas fields could diversify the economy of western Montana. Oil production is also a possibility, but current estimated reserves are insignificant.

Even if the most optimistic expectations are realized, Missoula is not likely to experience significant longrun effects from oil and gas development. Most of the impacts of gas and oil operations on employment and earnings are felt during the exploration and development stages; few workers are required to maintain an operational crude oil or natural gas well. Furthermore, the most promising areas of the Montana Overthrust Belt are east of the Continental Divide, so Great Falls and Billings would probably enjoy most of the benefits. If significant reserves of oil and gas are found in western Montana, Missoula's wholesale and retail trade sectors are likely to experience the greatest impacts.

Tourism and transportation did grow during the 1970-78 period, but these industries are a minor component of the export base and their future growth will be influenced by energy prices. Consequently, these industries are not likely to significantly influence the growth of the Missoula community.

In summary, none of the components of the export base of the Missoula community appear threatened in the near future; depending on the timber supply, that could change. Continued growth at rates experienced in the 1970's appears unlikely. The diversity of the export base may cushion any instability in the wood products industry.

Flathead Community and Spatial Interdependency

The wood products industry in the Flathead community did grow between 1970 and 1978. But this growth was a distant second to that exhibited by the primary metals sector of the export base. Furthermore, Flathead was less dependent on timber in 1978 than in 1970. A high proportion of the growth of the timber sector in Flathead was the result of increased utilization (for example, by the construction of a medium density fiberboard plant). At the same time, mill residues continued to be shipped to Missoula for processing. The future of the timber industry will depend on the supply of raw material, and the timber supply situation in Flathead could become more complicated. At present, Flathead is more dependent than Missoula on public timber, and timber processing plants in Flathead rely on nearby sources—importing only 30 percent of their sawtimber requirements. Seemingly, therefore, a decrease in the private supply would affect Missoula more than Flathead. But if the private timber supply is diminished, Missoula facilities, which already import considerable private timber from the Flathead community, may begin to compete more intensely for public timber which traditionally has been processed locally.

Primary metals refining was the major contributor to growth of Flathead's export base. This increase may not be repeated, because growth during the 1970's was a one-time event associated with the modification of the aluminum refinery at Columbia Falls. Furthermore, expanded production at this facility is unlikely because low-cost electricity is no longer available. Because it is now the largest component of the export base, primary metals could conceivably cushion instability in the timber sector.

Exploration activity in nearby areas of the "Overthrust Belt" may occur. But the most promising areas are east of the Continental Divide, and the economic impacts would be short run.

Tourism increased significantly from 1970 to 1978. Future growth will depend on energy prices, among other things. But this industry is only a minor component of the export base.

In summary, the future growth of the wood products industry in the Flathead community will depend on raw material supply. The primary metals industry is now the largest component of the export base and may cushion instability in the wood products sector. Significant growth appears unlikely in the remaining sectors of the export base.

[15] Dalton, G. L.; Carlson, K. H.; Charpentier, R. R.; Coury, A. B.; Crovelli, R. A.; Frezon, S. E.; Khan, A. S.; Lister, J. H.; McMullin, R. H.; Pike, R. S.; Powers, R. B.; Scott, E. W.; Varners, K. L. Estimates of undiscovered recoverable resources of conventionally producible oil and gas in the United States, a summary. U.S. Department of the Interior, Geological Survey, open-file report 81-192; 1981

Linn-Benton Community Likely To Experience Modest Growth

The timber industry was a major contributor to the growth of the Linn-Benton community during the 1970-78 period. It will undoubtedly be affected to some degree by any future shortfall in timber supplies in western Oregon. But the impact of any shortfall will not be as severe as in the timber-dependent areas of southwest Oregon (Beuter and others 1976).

The Linn-Benton community could attract additional computer-based industries. Hewlett-Packard will probably expand its Corvallis facility, and Tektronix, Inc., has announced plans to locate a plant in nearby Lebanon. Such expansion plans could counterbalance instability in the timber industry.

Although zirconium production may remain constant, the Linn-Benton community stands to benefit from the expected growth in demand for titanium (Marple and Parks 1982). Consequently, growth of primary metals, like growth of the computer-based industry, could counteract instability in the timber industry.

Oregon State University exhibited some growth during the 1970's, but higher education is no longer regarded as a growth industry. The recent recession has caused enrollment to drop, but prospects are good for long-term growth. Demographic changes as well as fiscal constraints, however, could result in slower growth in the future.

Despite the uncertain future of higher education and the possible decline of the timber industry, the export base of the Linn-Benton community will likely continue to grow at a modest rate. The primary metals and computer-based sectors are likely to counteract any instability in the timber industry. Furthermore, the economy of Linn-Benton is less "free standing" than that of the other communities. Future development of the economy of Linn-Benton will undoubtedly benefit from the expected growth of the larger metropolitan areas—Salem, Eugene, and Portland—of the Willamette Valley.[15]

Douglas Community Could Experience Adverse Impacts

Private timber production, which had been declining during the 1960's, stabilized during the 1970-78 period (Lloyd 1978). Harvesting from public lands, which had been increasing, leveled off. These trends may portend a more precipitous shortfall than earlier predicted. As Gudger and Smith (1972) observed, Hamill's (1963) prediction of a shortfall is optimistic to the extent that short-term private harvests deviate (upward) from long-term trends.

Douglas is the most timber-dependent community of the four communities we studied. Although there was some diversification (mainly the result of retirement income), the dominant position of the wood products industry is not likely to change in the near future. A California-based electronics firm recently (1982) announced plans to construct a new plant in Roseburg. This is encouraging, but several such facilities would have to be constructed to compensate for likely job losses in the timber-dependent sector.

In summary, the current lack of diversification in the economic base suggests that the Douglas community will not be able to attract new industries rapidly enough to counterbalance instability related to the expected timber shortfall.

[15] Lawrence Halprin and Associates. The Willamette Valley: choices for the future. Prepared for the Willamette Valley Environmental Protection and Development Planning Council. Salem, Oreg. 1972. 113 p.

Will the Future Timber Supply Be Diminished?

Even though we lack a comprehensive analysis, we believe the Missoula and Flathead communities may become more interdependent with regard to timber supply. According to USDA Forest Service plans, harvesting of Federal timber may increase slightly by the 1990's. Such an increase may not be large enough, or soon enough, to counteract any decrease in the private supply. Consequently, to the extent that levels of harvesting on private lands observed during the 1970's cannot be maintained, the timber industry in western Montana could be adversely affected.

The Linn-Benton community borders the north coast area which, according to Beuter and others (1976), may witness increased timber harvesting. Consesequently, local processing facilities may not be constrained by raw material shortages.

The Douglas community has been identified by many authorities as a future timber-deficit area; that is, local sources will likely not be able to supply local needs.

Is Dependency on Timber Significant?

The answer for each of the four communities is "yes." This was preordained by our choice of study areas. But there are differences in the degree of timber dependency. The situation, moreover, has not remained static, and there were some surprises. During the 1970-78 period, Missoula became more dependent on timber, and the Douglas community exhibited little evidence of diversifying.

Are Options to the Nondeclining Even-Flow Policy Feasible?

Lacking a comprehensive timber supply analysis, we cannot answer this question for the Missoula and Flathead communities.

According to Beuter and others (1976), feasible options to the nondeclining even-flow policy exist for western Oregon.

Could the Growth of Nontimber Industries Compensate for the Decline of the Timber Industry?

Missoula has a diverse export base, but continued growth at rates experienced during the 1970's is not likely. The diversity, however, could well cushion any instability in the wood products industry.

Growth of the nontimber sectors of the export base of the Flathead community is uncertain. Consequently, any shortage of timber may have an adverse impact on the economy of the community.

Several sectors of the export base of the Linn-Benton community are likely to continue growing. Such growth could compensate for timber shortages.

The nontimber component of the export base of the Douglas community is small. Even if these sectors grow at the 1970-78 rate during the 1980's, they will probably not compensate for predicted timber shortages.

The need for planners and analysts to consider long-term trends should be apparent. The 1970 outlook for the timber industries of Oregon and western Montana was too modest. Current forecasts, however, suggest that the extraordinary performance of the timber industry in Oregon will not be repeated in the 1980's. Similarly, the growth of primary metals in the Flathead community will not persist because the refinery modifications, which resulted in increases during the 1970's, have been completed. Finally, the resurgence of the timber processing sector of Missoula's export base reversed earlier trends, but continued growth of this sector will depend on the ability of the Missoula timber processing facilities to compete with other areas for the uncertain timber supply in western Montana.

Of the four communities examined, Douglas appears to be the prime candidate for considering departures from nondeclining even flow. The export base is dominated by the wood processing sector—diversification is not progressing rapidly enough to counteract the predicted shortfall in timber supply.[17/] Furthermore, there is evidence that public timber management practices could be modified to moderate the expected shortfall and, at the same time, not jeopardize the areas's long-term timber-producing capabilities.

Departure from NDEF may be appropriate for the western Montana communities. But because of the geographical proximity and, in particular, the overlapping timbersheds, the economic futures of the Missoula and Flathead communities should be jointly assessed before a decision is made about whether or not departures should be considered for public lands in western Montana. An ad hoc approach could result in a remedy that benefits one community at the expense of the other.

A comprehensive, multiownership analysis of the western Montana timber supply situation does not exist. Until such a study is undertaken, the departure issue cannot be appropriately considered.

[17/] Commercial banks in the Douglas community, unlike those in the Linn-Benton community, invested an increasing share of their funds outside the local area during the 1958-77 period (Schallau 1980). Such a trend could portend a leveling off in new business activity and population, other things being equal. The Douglas community experienced a net decline in migration during the 1960's. Data suggest that the Douglas community experienced an unprecedented drop in population in 1980 and 1981 (Oregon State Employment Division 1982); but the population growth rates exceeded those for the State of Oregon during the 1970's, so this 1-year decline may be an aberration.

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ppendix

xport Base Industries of athead, Missoula, Douglas, and nn-Benton Communities by tandard Industrial Classification IC) Codes

ble 23—Export industries of the athead community, Montana, by C code, 1972

lustry	SIC code
ricultural production	01, 02
ricultural services, restry, and fisheries	07-09
ning	10-14
ber and wood products	24
niture and fixtures	25
mary metals refining	33
nsportation equipment	37
lroad transportation	40
lesale trade (part)	50, 51
ail trade (part)	52-59
els, rooming houses, camps, d other lodging places	70
eral civilian	--
eral military	--

ble 24—Export industries of the ssoula community, Montana, by C code, 1972

ustry	SIC code
icultural production	01, 02
icultural services, restry, and fisheries	07-09
ng	10-14
rel	23
ber and wood products	24
niture and fixtures	25
and paper products	26
nicals and allied products	28
e, clay, and concrete ducts	32
road transportation	40
sportation by air	45
lesale trade (part)	50, 51
il trade (part)	52-59
ls, rooming houses, camps, other lodging places	70
ational services, State ernment (University of tana)	822
eral civilian	--
eral military	--

Table 25—Export industries of the Douglas community, Oregon, by SIC code, 1972

Industry	SIC code
Agricultural production	01, 02
Agricultural services, forestry, and fisheries	07-09
Mining, except quarrying	10-13
Meat products	201
Canned and preserved fruits and vegetables	203
Miscellaneous food preparation (fish)	209
Lumber and wood products	24
Pulp and paper products	26
Primary metals refining	33
Machinery, except electrical	35
Railroad transportation	40
Hotels, rooming houses, camps, and other lodging places	70
Federal civilian	--
Federal military	--

Table 26—Export industries of the Linn-Benton community, Oregon, by SIC code, 1972

Industry	SIC code
Agricultural production	01, 02
Agricultural services, forestry, and fisheries	07-09
Mining, except quarrying	10-13
Meat products	201
Canned and preserved fruits and vegetables	203
Grain mill products[1/]	204
Miscellaneous food preparation[1/]	209
Lumber and wood products	24
Furniture and fixtures	25
Pulp and paper products	26
Primary metal refining[1/]	33
Fabricated metal[2/]	34
Machinery, except electrical	35
Electrical machinery[1/]	36
Railroad transportation	40
Hotels, rooming houses, camps, and other lodging places	70
Educational services, State government (Oregon State University)[1/]	822
Engineering, architectural, and surveying services[1/]	891
Federal civilian	--
Federal military	--

[1]Linn County.

[2]Benton County.

Schallau, Con H; Polzin, Paul E. Considering departures from current timber harvesting policies: case studies of four communities in the Pacific Northwest Res. Pap. PNW-306. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 29 p.

U.S. Department of Agriculture regulations permit departures from current National Forest timber harvesting policies when "implementation of base harvest schedules . . . would cause a substantial adverse impact upon a community . . .." This paper describes the kinds of information needed for forest managers to adequately assess the relevance of the departure issue to particular planning units. The relevance of the departure issue varied, depending on: (1) future timber supply, (2) timber dependency, (3) the long-term feasibility of alternatives to current timber harvesting schedules, and (4) whether or not the growth of industries not dependent on timber might compensate for a timber shortage.

Keywords: National Forest policy, economic impact, economic importance (forests), timber harvesting policy, harvest scheduling, timber supply.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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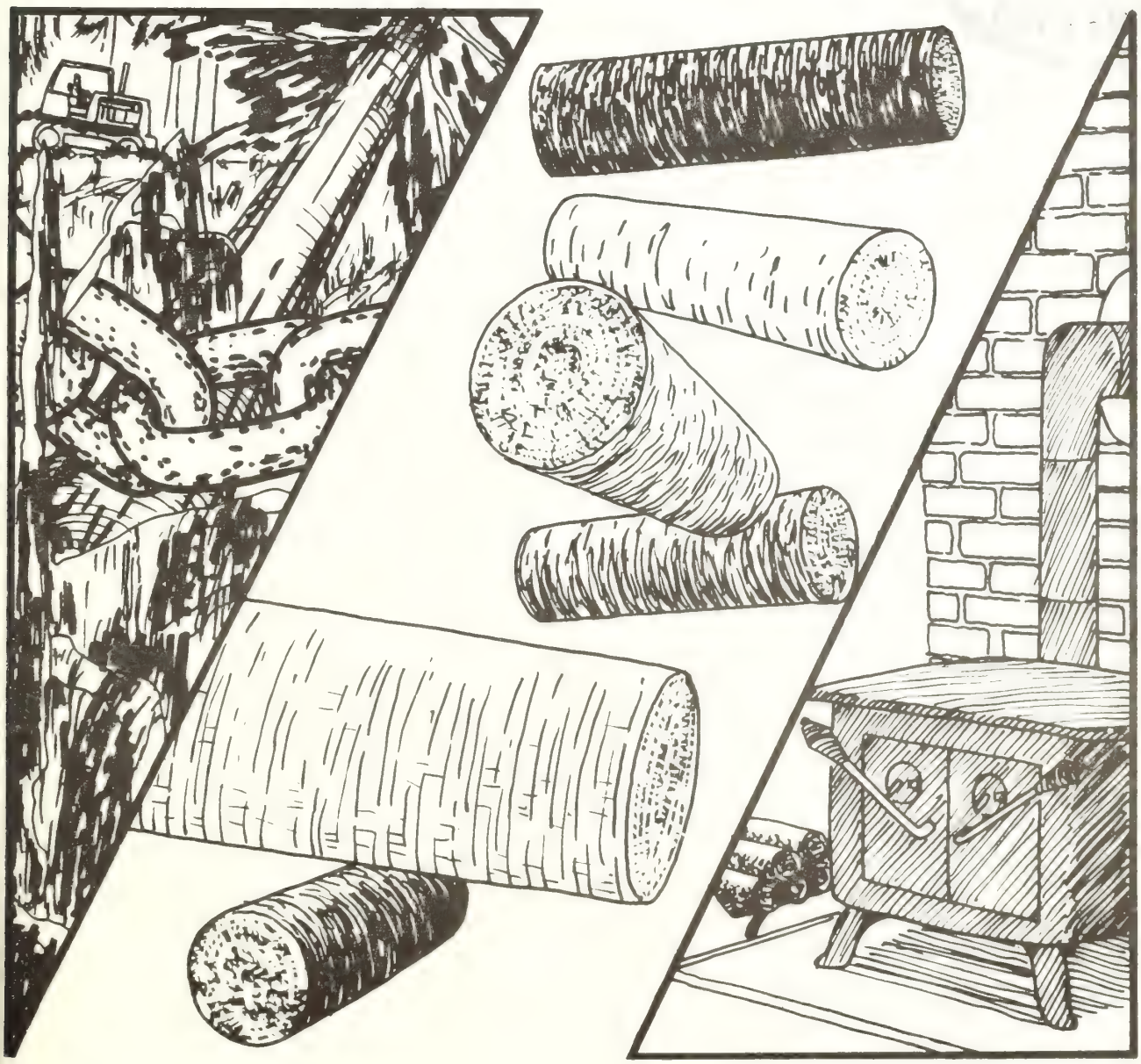
Potential for Economical Recovery of Fuel From Land Clearing Residue in Interior Alaska

George R. Sampson and Forrest A. Ruppert



Authors

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Abstract

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Unusable tree and moss residues from land clearing projects in interior Alaska were collected, milled, dried, and densified into fuel logs. Four different combinations of species were tried, and all produced suitable fuels. The feasibility of commercially producing this material into densified fuel in interior Alaska is limited because the fuel logs tend to expand or decompress during winter storage in unheated buildings there.

Keywords: Wood waste utilization, fuel (waste wood), fuel (pressed wood), energy, residues.

Summary

Land clearing for agricultural use in interior Alaska results in residue that must be disposed. The residue could have potential use as home heating fuel. Researchers studied the feasibility of economically converting land clearing residue into densified fuel logs.

A manufacturer of densified fuel logs made from plywood mill residue, located in Grants Pass, Oregon, produced experimental fuel logs using four types of land clearing residue from interior Alaska: black spruce, moss, a mixture of paper birch and aspen, and a mixture of moss and black spruce. The logs were 3 inches in diameter and 10 inches long. People who burned the experimental fuel logs in their home heating systems liked spruce and the mixture of paper birch and aspen, but they generally did not like the moss fuel logs as well as firewood. The moss logs burned slowly, smoked, and left a high proportion as ash. Fuel logs stored in covered but unheated storage over winter tended to decompress during the transition to summer; fuel logs stored in covered, heated buildings did not.

The costs of manufacturing densified fuel logs from land clearing residue in interior Alaska make the product marginally competitive with firewood. Capital investment, however, is quite high, and a large share of the local firewood market would have to be captured for a manufacturing plant to be profitable.

Introduction

A large-scale program to develop agriculture in Alaska was begun by the State of Alaska in August 1978. Nearly 60,000 acres of State land in the Delta Junction area, southeast of Fairbanks, were transferred by sale of agricultural rights to private interests for clearing and conversion to crop land. This first agricultural sale by the State is referred to as the Delta Agricultural Project (fig. 1). The sale was followed by disposal of 24,425 acres in Delta II East in 1982. Other small-scale disposals have been made for agriculture, and more disposals—both large- and small-scale—are planned for the future.

Many owners clear tree cover from their land by dragging a ship anchor chain between two large crawler tractors. Because of fire hazard, the chained material cannot be burned in place; trees and the underlying moss layer are pushed into berm rows (fig. 2). After drying for a summer, the berm rows are burned in late fall or winter. Repeated burnings are necessary over several years before the material is reduced enough to be removed. The practice has been to farm between the berm rows until all the material is finally removed.

If merchantable sawtimber were harvested prior to chaining, a substantial volume of woody biomass and the moss layer would still remain as a disposal problem. Many of the black spruce stands contain no merchantable timber. The volume of biomass in a typical lowland black spruce stand is summarized in table 1. The majority of the biomass in such stands is in the moss layer.

One alternative to burning the biomass onsite is to remove and utilize it as a fuel (Eakin 1979, Lewis 1979). This would almost certainly require that the biomass be chipped onsite and be dried and densified at a nearby location. Most of the commercial wood densifying operations in existence today use dry sawmill or plywood residue as raw material. It was not known whether the kinds of biomass present on a typical site could be successfully processed through a commercial densifying operation to produce fuel logs or briquettes.

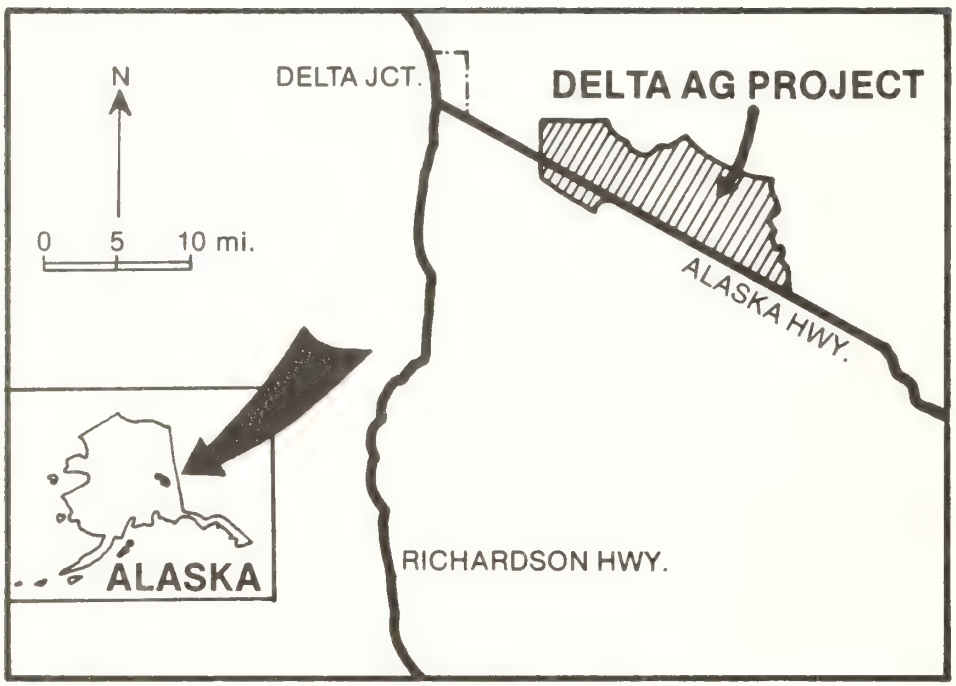

Figure 1.—Location of the Delta Agricultural Project.

Table 1—Composition of biomass in a "typical" lowland black spruce stand in interior Alaska

Type of biomass	Tons/acre	Percentage of total biomass
Moss, upper layer	17.14	26.5
Moss, lower layer	37.50	58.0
Standing overstory tree material	7.19	11.1
Standing dead timber	.98	1.6
Dead and down timber	1.17	1.8
Herbaceous vegetation	.66	1.0

Source: Eakin and others 1979.

Figure 2.—The land clearing operation in the black spruce type in interior Alaska: *A*, trees are uprooted by chaining; *B*, chained material is piled into berm rows and burned.

Purpose of the Study

The purpose of our study was to determine if a densified fuel could be made from typical land clearing residue from interior Alaska and to determine the characteristics of such a fuel, if it could be successfully produced. Whether or not it is feasible to make a fuel from land clearing residue is an important question; there are plans to have 500,000 acres of land cleared for agriculture in interior Alaska by 1990. Virtually all of this land is covered by forest and moss.

Methods

Four types of material were selected for study: (1) the moss layer under a typical black spruce (*Picea mariana* (Mill) B.S.P.) stand, (2) whole tree black spruce, (3) a mixture of moss and black spruce, and (4) a mixture of paper birch (*Betula papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx.). All materials were collected on or adjacent to the Delta Agricultural Project. The moss layer, which includes all organic matter in this forest floor above mineral soil, was collected by hand in an undisturbed black spruce stand to minimize the amount of dirt and stones in the sample. Black spruce trees were taken from material in berm rows that had already been chained and piled. Whole trees were taken, including attached roots, needles, twigs, and bark. For the paper birch-aspen mixture, whole trees were taken including the bole, bark, twigs, and leaves, but excluding roots.

The residue, each type kept separate, was shipped by barge from Alaska and trucked to Washington State University where it was hammermilled and dried. Wood materials were chipped and then processed through a small industrial size hammermill with a 5/8-inch screen. Three different particle sizes were produced from the moss samples. Coarse moss was material that did not pass through a number 4 Tyler[1/] screen (sieve with 0.187-inch openings). Medium moss passed through a number 4 screen, but not a 32 screen (sieve with 0.0197-inch openings). Fine moss passed through a number 32 screen. The material was then shipped to Fourply, Inc. at Grants Pass, Oregon, for densification. Different combinations of all materials were made based on nearly dry weight (about 10 percent moisture content). The moss-black spruce mixture was 70 percent moss and 30 percent black spruce. The paper birch-aspen mixture was 60 percent paper birch and 40 percent aspen.

1/ Trade and company names are used for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

The residue was mixed in appropriate proportions at Fourply, Inc. Proper proportions were weighed out then mixed with shovel in a pickup bed. The combinations of material represented what will likely be encountered on land clearings in interior Alaska. Much of the land to be cleared is covered by black spruce underlain by a thick layer of moss, represented by the mixture of moss and black spruce. It would also be possible to harvest either the moss or black spruce separately. Other lands to be cleared are covered by mixed stands of paper birch and aspen with little moss beneath the stands. The most appropriate way of removing this timber is to shear it at or near ground level, taking the entire tree.

All material was processed through the commercial fuel log machine.[2/] In the process, a 3-inch diameter continuous log was extruded into a long cooling line, then was broken into 10-inch lengths by a pneumatic device. The individual logs were carried by conveyor belt to the packaging area.

Samples of each type of experimental fuel and commercial product produced were sent to the University of Washington where calorific values and residual ash content were determined. Samples of the experimental fuel logs were given to interested individuals around Portland, Oregon, and Fairbanks, Alaska, for burning in their home wood-burning stoves or fireplaces. These individuals were given a questionnaire which asked them to subjectively compare the experimental fuel logs with their usual fuel. Samples of each type fuel log were placed in both covered and exposed storage in the Fairbanks area to determine long-term deterioration rates.

2/ A Hausmann Briquettor manufactured by Fred Hausmann, Ltd., of Basel, Switzerland. The machine is operated by Fourply, Inc., of Grants Pass, Oregon.

Results

With one exception, all types of material were compressed into fuel logs with no major production problems (fig.3). The fine moss material that passed through a number 32 screen did not process well because of excess friction in the cooling line at start up. This fine moss material looked and felt like very fine sand and, in fact, contained a high proportion of fine soil particles. When mixed with wood particles or larger size moss material, however, the fine moss processed satisfactorily. Except for the very fine moss, there were no differences noted in how effectively the raw materials were densified. There were no additives: the process depended only on pressure for successful densification. Weights of the fuel logs produced during the test run are summarized in table 2. Weights per fuel log are greatest for moss, followed by moss-spruce, spruce, then birch-aspen. This is a direct reflection of density of the parent material.

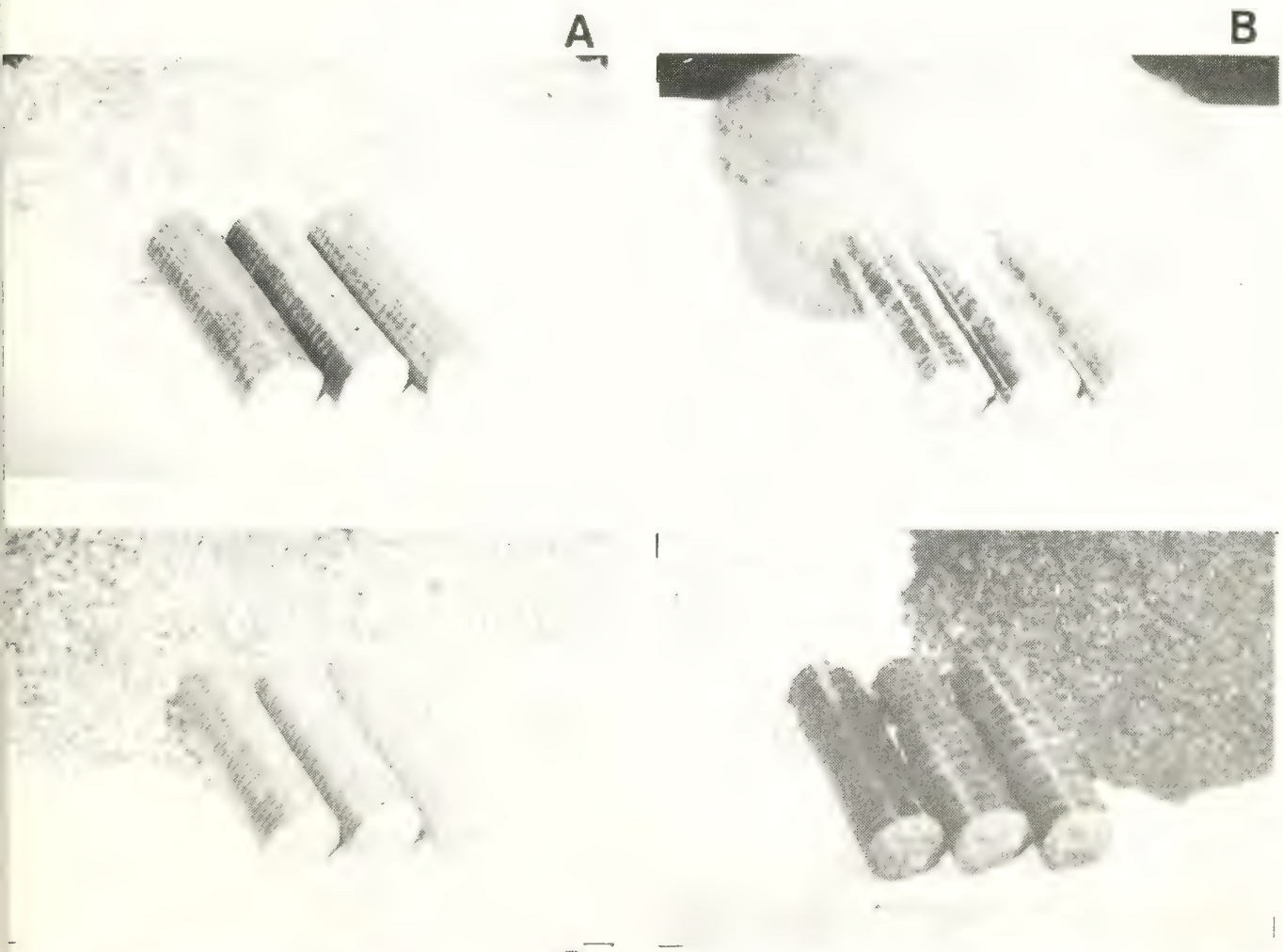

Figure 3.—Densified fuel logs with comparable amount of hammermilled raw material: *A*, black spruce; *B*, moss, *C*, mixture of paper birch and aspen; *D*, mixture of moss and black spruce.

Table 2—Weight of fuel logs produced from land clearing biomass in interior Alaska by type of material

Type of material	Number of fuel logs weighed	Weight per fuel log		
		Range	Average	Coefficient of variation
		------- Ounces -------		percent
Birch-aspen mixture	30	45-46	45.5	1.1
Spruce	30	46-48	47.1	1.2
Coarse moss	30	51-57	53.4	2.7
Medium moss	30	53-60	56.4	2.6
Moss-spruce mixture	30	51-56	53.3	2.8
Commercial product [1]	15	44-46	44.7	1.1

[1] Produced from a mixture of Douglas-fir, ponderosa pine, and white fir veneer and plywood trimmings.

Table 3—Higher heating values and ash content of samples from fuel logs produced from land clearing biomass in interior Alaska by type of material [1]

Type of material	Number of samples	Higher heating value		Ash content	
		Average	Coefficient of variation	Average	Coefficient of variation
		BTU/pound	percent	percent	percent
Birch-aspen mixture	32	8686	1.6	1.5	33.3
Spruce	32	8767	0.6	1.7	47.1
Coarse moss	32	6734	2.7	24.8	8.5
Medium moss	32	6429	6.5	29.7	3.0
Fine moss	6	4505	23.6	47.8	4.4
Moss-spruce mixture	32	6927	4.5	24.1	18.7
Commercial product [2]	31	8771	6.3	1.2	4.4

[1] Values are based on ovendry weight.
[2] Produced from a mixture of Douglas-fir, ponderosa pine, and white fir veneer and plywood trimmings.

Initial plans were to determine breakage of fuel logs as they came from the conveyor belt. The only breakage that occurred, however, was in briquettes produced immediately after changing to a different raw material type. A sample of the fuel logs was put in cardboard boxes, placed on pallets, and shipped from Oregon to Alaska by commercial ocean freighter. By the time the fuel logs arrived in Fairbanks they had been handled at least four different times, enough to be an adequate test of breakage in transit. There was no evidence of fuel log breakage on arrival in Fairbanks.

The maximum potential energy or higher heating values of samples from the fuel logs are shown in table 3. Spruce had the highest heating value at about 8800 BTU's per pound, followed by birch-aspen at 8700, moss-spruce at 6900, coarse moss at 6700, medium moss at 6400, and fine moss at 4500. Table 3 also shows ash content: the relationship is the inverse of energy content. The values of energy and ash content obtained are approximately what was expected, with the exception of the medium moss and, particularly, the fine moss. The decreasing energy content and increasing ash content as moss particle size decreased were apparently the result of increased mineral content, principally soil.

Individuals who burned some of the fuel logs in their home heating systems liked the nonmoss fuel as well or better than their usual firewood (table 4). They generally did not like the moss fuel logs as well as their usual fuel, however, because they burned slowly and had a high ash content.

Table 4—Results of subjective burning tests of experimental fuel logs compared to usual fuel of split firewood in home heating systems

Question asked user	Type fuel log burned			
	Paper birch-aspen	Black spruce	Moss	Moss-black spruce
	Number of responses			
Did you have a problem igniting the fuel log?				
Yes	4	5	8	7
No	7	8	2	1
No answer	1	1	0	0
Does it heat as well or better than your usual fuel?				
Yes	9	9	1	4
No	3	3	8	4
No answer	0	2	1	0
Is as clear or clearer than your usual fuel?				
Yes	11	9	4	3
No	0	3	6	5
No answer	1	2	0	0
Did the fuel log burn as long or longer than your usual fuel?				
Yes	6	6	8	8
No	4	4	2	0
No answer	2	4	0	0

The fuel logs were resistant to disintegration from very humid conditions when exposed for a short time. That is, they survived several days on an ocean barge with no ill effects. Initially, they also appeared resistant to disintegration from very dry conditions or from changes in temperature (-40°F to 90°F). Fuel logs stored over winter in covered but unheated storage, however, expanded linearly 25 to 30 percent with the advent of summer temperatures. We suspect this was caused by a combination of high relative humidity and repeated freezing and thawing. Generally, the spruce fuel logs showed greatest expansion, followed by paper birch-aspen and then fuel logs derived from moss material.

Some logs were stored together in a greenhouse over winter and were taken outdoors to be photographed in May (fig. 4). The spruce fuel log had expanded from its original 10 inches to 13, birch-aspen to 12, and moss to about 11 inches. Other logs were placed outside in November. They remained intact after a light snow when temperatures remained well below freezing, but rain initiated rapid disintegration (fig. 5). Covered storage and transport of fuel logs is therefore essential at all times. Fuel logs stored in heated space have not shown a tendency to disintegrate.

Extruded particle board, which should have characteristics similar to extruded fuel logs, has a tendency to swell in the lengthwise direction because of the compression and orientation of particles from the extrusion pressures (U.S. Department of Agriculture, Forest Service 1974). A recently completed study concluded that none of the current commercial processes can densify biomass into fuel without a binder to produce a product that is water stable—one that can be stored exposed to weather 60-90 days (Levelton and Associates Ltd. 1981).

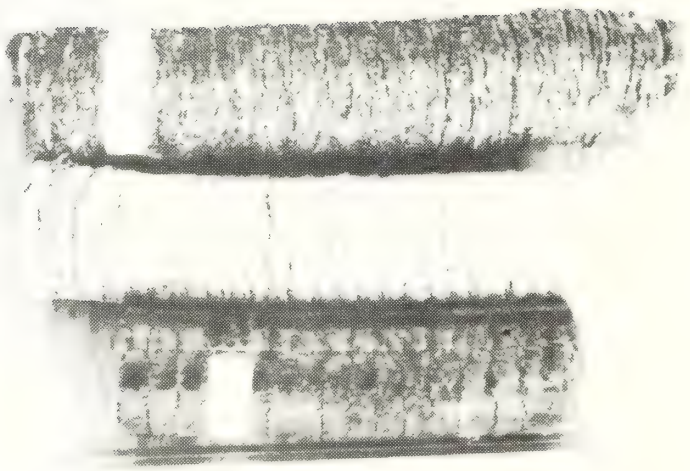

Figure 4.—Expanded fuel logs after winter storage in an unheated greenhouse. From top to bottom: spruce, birch-aspen, and moss.

Figure 5.—Disintegrated logs stored outdoors.

Discussion

Procedures used in this study to collect and process the material involved much hand and labor and were not typical of practices that would be employed by a commercial operation. A commercial operation would likely chip raw material directly from berm piles. Proper clearing technique requires that about 2 inches of moss layer be left behind when the material is piled. The remaining moss is then incorporated into the soil during piling. Thus, there should be a minimum of free soil and dirt in the berm piles. Some soil and rocks may cling to tree roots after uprooting, but most would be dislodged and screened out in the chipping process and would not affect the densification process. There is, however, a substantial quantity of mineral matter incorporated in the moss layer in the Delta Junction, Alaska, area that cannot be removed by any known practical means. Its presence is the result of decades of windblown particles being taken from glacial streambeds, deposited on trees, then filtered into the moss layer. This incorporated soil did not appear to directly affect either the chipping of our raw material or the densification of our sample fuel logs, but the densified moss had a coal-like appearance, being black in color. The major disadvantage of the incorporated soil is the large proportion left as residual ash after burning—the ash content of the moss is 25-30 percent by weight. The high residual ash in moss is undoubtedly a function of geographic location. Preliminary tests of moss from the Little Chena River drainage northeast of Fairbanks indicate only 3 to 7 percent residual ash.

Material left in berm piles for more than a year will undoubtedly begin to decay, yet the decay does not appear to be a problem when the material is chipped or densified.

The problem of decompression and subsequent disintegration of fuel logs stored in unheated storage over winter could be avoided by shrink-wrapping the logs in groups of two to four, but only at great increase in cost. The shrink-wrap would have to be burned with the fuel logs, a possibly unacceptable requirement for people heating mainly with wood. The tendency of the fuel to decompress and disintegrate might be less of a problem if it were made into pellets, but expansion of fuel pellets in a bin from which a stoker system operates could present feed problems. Care would have to be taken to insure that the atmosphere around storage bins be quite dry.

Production costs of making fuel logs from land clearing residue are largely dependent on assumptions about what equipment is going to be purchased and operating efficiency. Obviously, an enclosed, heated building is essential for manufacturing fuel logs during the winter in interior Alaska. In addition to a chipper and trucks for hauling chips, a hammermill, drier, and densifier would be needed as well as a shed for storing fuel logs. The most efficient operation we can envision within the size constraints imposed by local markets would require a capital investment of over three-quarters of a million dollars; the operation would produce more than 15,000 tons per year of densified fuel logs (less than one-fourth of the current annual consumption of firewood in Fairbanks North Star Borough). Total costs of field chipping, hauling, and manufacture would be in the range of $55-$65 per ton, making densified fuel logs cost competitive with firewood. Firewood currently commands a delivered price of more than $100 per cord in the Fairbanks area.

Conclusions

The feasibility of commercially producing densified fuel logs from the biomass from land clearing projects remains questionable unless some method is found for preventing the fuel logs from decompressing when they are stored over winter.

It does not appear feasible to densify the moss layer when it has a high mineral content, such as the 25 to 30 percent found in the Delta Junction area. This high mineral content tends to impede the burning rate in home heating systems and also results in an objectionably high residual ash. Moss from areas that are not subject to prevailing winds carrying silt from glacial streambeds may be suitable for densification into fuel logs, but such material was not tested in this study.

Densified fuel logs from land clearing biomass cannot be marketed at a price competitive with coal for large-scale users such as electric utilities with rail access. The fuel logs could be only marginally price competitive with coal for home heating systems in the Fairbanks area or other areas where coal can be brought in by rail. Densified fuel logs can be price competitive with dried, cut-to-length firewood. An investment of about $750,000 would be required to establish a densified fuel log business. Marketing its products would require capturing the equivalent of one-fourth to one-third of the firewood used annually in the Fairbanks North Star Borough. Capturing such a large volume of the market in the span of several years does not appear possible even though public access to timber for firewood has become a problem.

The most economical beginning for producing densified fuel in interior Alaska would be by an operating wood products processing plant that already has a supply of residue onsite and may also have some slack labor available. This would help offset the diseconomies of a small operation, but would enable the entrepreneur to begin production with a small market volume of 2,000 to 4,000 tons per year. Such an operation could expand into using land clearing residue after several years of market development.

Acknowledgment

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Wind Adjustment Factors for Predicting Fire Behavior in Three Fuel Types in Alaska

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Abstract

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Factors for adjusting wind velocities from the 20-foot standard anemometer height down to an average wildfire midflame height (3.5 ft for the fuels studied) are given for exposed, partially sheltered, and sheltered fuels in Alaska. The values are suitable for predicting wildfire behavior.

Keywords: Fire behavior (forest), wind velocity, wind (-fire danger, fuels (forest fire), fuel management.

Introduction

The velocity of wind at the midflame height—3.5 ft (1.07 m) above the surface fuels in this case—is one of several variables required to estimate fire behavior by the system developed by Rothermel (1972, 1983). Albini (1976) and Burgan (1979) developed ways to use the system in the field. Most weather forecasts and recording stations give the windspeed at the standard 20-ft (6.1 m) height as described by Hardy and others (1955). An adjustment from the 20-ft height to the midflame height is needed because air flowing over the surface of the earth encounters friction that slows its movement, especially near the ground. Consequently, the windspeed at the 20-ft height is always greater than at the midflame height. The average midflame height varies from one wild-land fuel type to another and even within a given fuel type as environmental conditions change, but average values are used.

The fire behavior prediction system (Rothermel 1983) provides wind adjustment factors for fire in fuel types described as exposed, partially sheltered, or sheltered. The wind adjustment factor is the ratio of the windspeed at midflame height to the windspeed at 20-ft height, expressed as a decimal fraction. Wind adjustment factors for exposed fuels range from 0.36 to 0.55. The adjustment factor for partially sheltered fuels is 0.25, and factors for sheltered fuels range from 0.08 to 0.17.

Description of the Study

Alaska has unique fuel types that require special analysis if fire behavior predictions are to be accurate. Three common and important wild-land fuel types were chosen for a study of their physical and phenotypical responses to seasonal and short-term environmental influences. The very flammable black spruce/feathermoss (*Picea mariana* (Mill.) B.S.P./ *Hylocomium splendens-Pleurozium schreberi*) forests were given the most attention. The tussock tundra fuel type—consisting of *Eriophorum vaginatum* (L.) tussocks and various prostrate shrubs, herbs, and mosses—was selected because of its extensive distribution and recognized flammability. Because of their notable resistance to burning, the widely occurring deciduous tree forest types—paper birch (*Betula papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx.)—were also selected for study.

Measuring instruments were placed at 19 sampling sites selected in 1980; 13 of these sites were located along 55 miles of the Melozitna River, which forms a confluence with the Yukon River at Ruby, Alaska. These 13 sites are reported on here; 5 are in black spruce stands, 4 in tussock tundra, and 4 in hardwoods.

While the standard National Fire-Danger Rating System weather data and live and dead fuel samples were being collected, the standard 20-ft windspeed and the midflame windspeed were recorded at each site as close to 2:00 p.m. (Alaska daylight time) as possible (fig. 1). A typical installation is shown in figure 2.

Because of the varying height of the upper level of the surface fuel, the precision of the vertical placement of the midflame anemometer was ± 0.5 ft. Interviews with experienced firefighters yielded the consensus that flame lengths of surface fires in these fuel types range from 2 to 5 ft under commonly encountered wildfire conditions. The cost of instrumentation dictated that a common value for the height of the midflame windspeed measurement be used; 3.5 ft was chosen.

Figure 1.—Windspeed at midflame height (3.5-ft) and 20-ft windspeed were measured simultaneously.

Figure 2.—Weather station installation on tussock tundra.

Instrumentation and Data Collection

Anemometers were permanently installed 20 ft above the vegetation (fig. 2) on each site, and a portable anemometer for measuring midflame windspeed was mounted on a staff (fig. 1). All anemometers were maintained to start at a windspeed of 1 mile per hour (mi/h) or less. Standard electronic contacting anemometers were used, with their 1/60-mile contacts connected to accumulating counters. The anemometer for measuring windspeed at midflame height was located away from the weather shelter or other artificial obstruction and at a spot most typical of the conditions on each site. The counters for both anemometers were started simultaneously, to the nearest second. The time of measurement (also to the nearest second) and the number of contacts generated by each anemometer were recorded at the end of each sampling period; 10 minutes was the shortest recording period allowed. The windspeed was then calculated by the equation:

$$\text{Windspeed (mi/h)} = \frac{\text{number of contacts}}{\text{number of minutes}}.$$

One pair of values was collected at each site daily. Of the windspeed measurements taken, 71 pairs were on black spruce sites: 34 on hardwood sites; and 68 on tundra sites.

Results

Paired values of 20-ft and midflame windspeeds from the black spruce, tussock tundra, and deciduous tree sites were recorded individually. The goal was to find the ratio of the midflame windspeed to the 20-ft windspeed, so a simple average ratio of these daily measurements was calculated (tables 1, 2, and 3). Simple linear regression equations were then calculated for the paired values from each site. The results are listed in tables 1, 2 and 3 under "Regression equation." The coefficient of determination (r^2) and the standard error of the regression ($S_{y \cdot x}$) are also listed. Because the density of a stand of trees strongly influences the wind reduction factors, the percentage of canopy cover of the forested sites is also listed in tables 1 and 3.

The regression equations for each fuel type were tested for differences at the zero intercept and for slope among sites. Where there was no significant difference (90-percent confidence level), all pairs of windspeed values for that fuel type were pooled, and an overall simple linear regression equation was calculated.

Table 1—Wind adjustment values and associated data for black spruce stands in Alaska

(x = 20-ft windspeed—miles per hour; y = midflame windspeed—miles per hour)

Site number	Simple average ratio	Regression equation	r^2	$S_{y \cdot x}$	Canopy cover
					Percent
1	0.13	y = 0.13 + 0.11x	0.81	0.25	80
2	0.24	y = 0.25 + 0.21x	0.91	0.54	45
3	0.22	y = 0.07 + 0.20x	0.81	0.51	40
4	0.30	y = 0.38 + 0.46x	0.92	0.32	45
5	0.15	y = 0 + 0.17x	0.84	0.37	40
2, 3, 5 (pooled)	0.21	y = 0.10 + 0.21x	0.85	0.53	—

Table 2—Wind adjustment values and associated data for tussock tundra sites in Alaska

(x = 20-ft windspeed—miles per hour; y = midflame windspeed—miles per hour)

Site number	Simple average ratio	Regression equation	r^2	$S_{y \cdot x}$
1	0.69	y = -0.10 + 0.70x	0.98	0.83
2	0.75	y = -0.04 + 0.76x	0.99	0.45
3	0.78	y = -0.23 + 0.81x	0.99	0.54
4	0.72	y = -0.72 + 0.83x	0.99	0.67
1, 2, 3, 4 (pooled)	0.75	y = -0.12 + 0.75x	0.99	0.68

Table 3—Wind adjustment values and associated data for hardwood sites in Alaska

(x = 20-ft windspeed—miles per hour; y = midflame windspeed—miles per hour)

Site number	Simple average ratio	Regression equation	r^2	$S_{y \cdot x}$	Canopy cover
					Percent
	0.31	y = -0.02 + 0.36x	0.92	0.74	85
2	0.27	y = -0.06 + 0.29x	0.90	0.52	75
3	0.43	y = -0.31 + 0.53x	0.95	0.71	25
4	0.31	y = 0.01 + 0.31x	0.91	0.38	75
, 2, 4 (pooled)	0.31	y = 0.02 + 0.31x	0.85	0.50	—

Discussion of Results

Within the black spruce fuel type, the wind adjustment factors for sites 1 and 4 were significantly different from the others, probably because of differences in stand structure; therefore, sites 2, 3, and 5 were pooled to give the regression equation listed under "pooled" values in table 1.

No statistically significant differences were found among any of the tussock tundra sites, so the values for all sites were pooled. The resulting regression equation is reported under "pooled" values in table 2, along with its associated statistics.

One hardwood site was significantly different from the other three, probably because of its exposed location on a ridgetop and its open stand structure. Site 3 was segregated, and the remaining values were pooled to get the regression equation at the bottom of table 3.

Notably, the adjustment factors for the tundra sites exceed any wind adjustment factors recommended for use by fire behavior officers (Rothermel 1983). The tussock tundra is an exceptionally smooth, homogeneous surface (fig. 2). Consequently, the midflame windspeed is fully three-fourths that of the 20-ft windspeed.

The structure of black spruce forests in Alaska is quite variable, as the data in table 1 indicate. The simple average rates for black spruce site 1 is 0.13, and the value for site 4 is 0.30. Site 1 is a dense, closed stand with a canopy cover of 80 percent. Site 4 is on the upper one-third of a very exposed ridge where moving air can penetrate the stand. It has a canopy cover of only 45 percent. The other three stands are apparently more typical of interior Alaska and fit the category of partially sheltered fuels as described by Rothermel (1983). A wind adjustment factor of 0.21 seems appropriate because the slope of the regression line is also close to that figure.

The wind adjustment factors for hardwood sites are surprisingly high, indicating that these open stands permit air to flow freely through them. The slope of the regression line for the three pooled sites is 0.31, putting them in the range of fuels described as exposed by Rothermel (1983). This is probably due to the absence of tree branches near the ground.

The regression equations for the pooled values from each fuel type probably represent typical situations in interior Alaska, although more measurements would be useful. Further, in most cases the zero intercept is so small that the slope of the regression line can be used as an adjustment factor with little error, simplifying the procedure for field use. Table 4 lists the values to be used for fuels in Alaska. To obtain an estimate of the midflame windspeed on tussock tundra, multiply the 20-ft windspeed (forecasted) by 0.75. Do likewise in typical black spruce, using 0.21; and in hardwoods, 0.31. If the black spruce forest is very dense, with canopy cover near 80 percent, the values published by Rothermel (1983) for fully sheltered fuels should be followed. The equation for black spruce site 1 suggests a value of 0.11. In very open black spruce stands on exposed ridges, a value as high as 0.46 may be suitable. Open hardwood stands on exposed ridges may require the use of a wind reduction factor as high as 0.53.

Table 4—Recommended wind adjustment factors for 3 types of fuel in Alaska

Fuel	Adjustment factor [1]
Black spruce:	
Dense, mature stands on flat or rolling terrain	0.11
Open stands or dense stands on the upper 1/3 of exposed ridges	.21
Very open stands on exposed ridges	.46
Tussock tundra	.75
Hardwoods:	
Birch or aspen stands on flat or rolling terrain, with leaves on trees	.31
Birch or aspen stands, widely spaced or on the upper 1/3 of exposed ridges	.53

[1] These values should be used only for stands in the interior of Alaska.

Conclusions

Some important conclusions may be drawn from these findings. Anyone forecasting wildfire behavior in Alaska should note the large difference in wind adjustment factors between these three commonly encountered fuel types. The value for tussock tundra should be given special attention because it is substantially higher than any wind adjustment factor previously suggested for fire behavior predictions. If a fire moves from a black spruce forest onto a tussock tundra, a threefold or greater increase in midflame windspeed can occur without any change in the 20-ft windspeed. Consequently, a very rapid increase in rate of spread should be anticipated. The same possibility should be considered when prescribed fires that include both the black spruce and tussock tundra fuel types are planned. The prescription limits should consider the much higher effective windspeed on tussock tundra portions of a proposed prescribed fire area. Although the surface fuels in hardwoods in Alaska are meager and fires in these forests are notably mild, the relatively high midflame windspeeds can carry fire when conditions are right.

The possible transition from one wind adjustment factor to another during a fire within a fuel like the black spruce type must also be considered. A fire beginning in a dense black spruce stand may require a wind adjustment factor as low as 0.11 (see table 1). As the fire grows to several thousand acres, however, the wind will be blowing across the barren, burned area which will then have a much higher wind adjustment factor. Therefore, wind adjustment factors in dense black spruce stands may be much lower for small fires than for very large fires, and they may change as the fire grows.

Summary

Simultaneous measurements of the speed of the wind at the 20-ft standard height and at 3.5 ft above the surface fuels (midflame height) lead to the wind adjustment factors given in table 4.

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Norum, Rodney A. Wind adjustment factors for predicting fire behavior in three fuel types in Alaska. Res. Pap. PNW-309. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 5 p.

Factors for adjusting wind velocities from the 20-foot standard anemometer height down to an average wildfire midflame height (3.5 ft for the fuels studied) are given for exposed, partially sheltered, and sheltered fuels in Alaska. The values are suitable for predicting wildfire behavior.

Keywords: Fire behavior (forest), wind velocity, wind (-fire danger, fuels (forest fire), fuel management.

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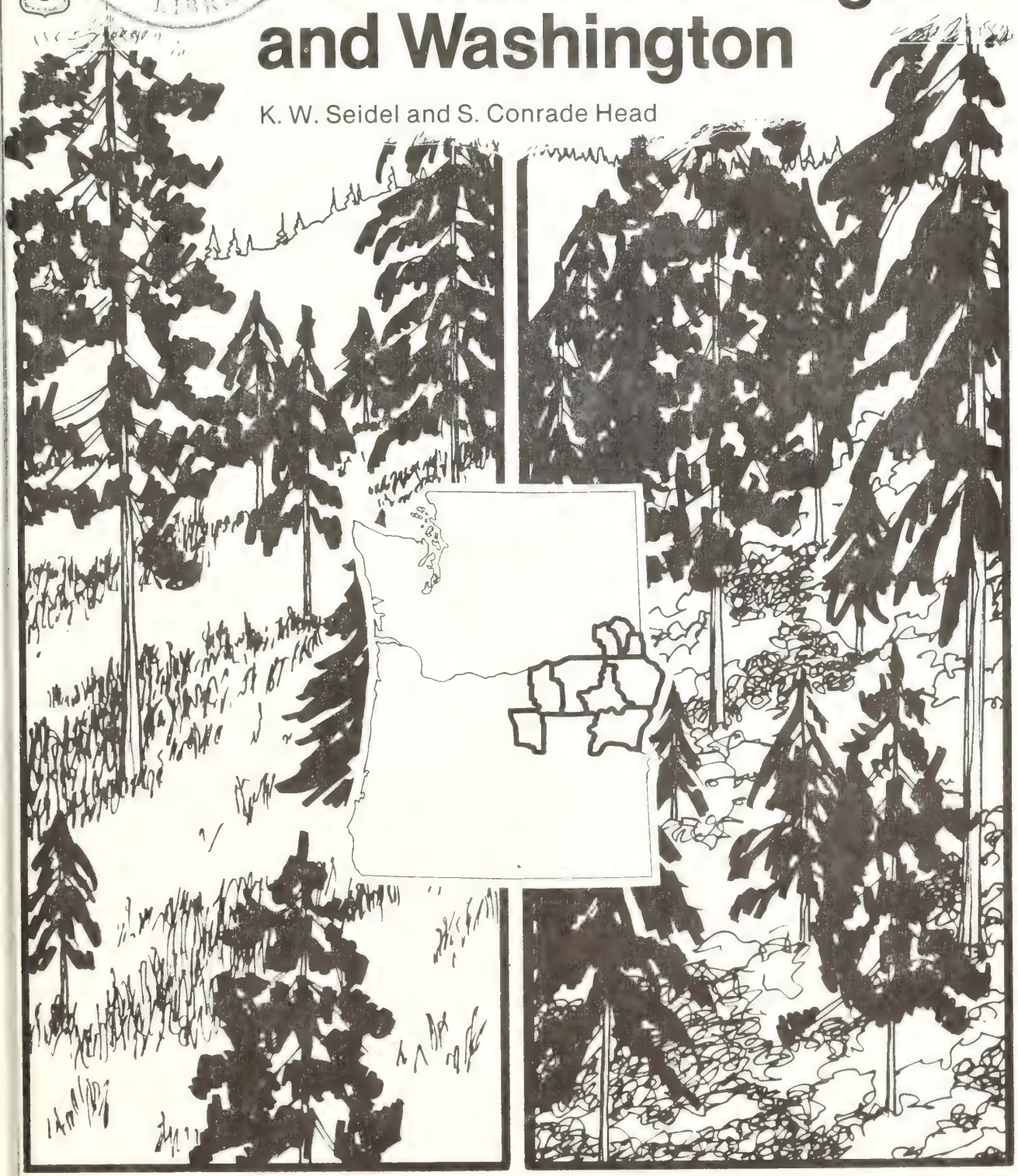
Regeneration in Mixed Conifer Partial Cuttings in the Blue Mountains of Oregon and Washington

K. W. Seidel and S. Conrade Head



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Abstract

Seidel, K. W.; Head, S. Conrade. Regeneration in mixed conifer partial cuttings in the Blue Mountains of Oregon and Washington. Res. Pap. PNW-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 14 p.

A survey in the Blue Mountains of northeastern Oregon and southeastern Washington showed that, on the average, partial cuts in the grand fir/big huckleberry community were well stocked with a mixture of advance, natural postharvest, and planted reproduction of a number of species. Partial cuts in the mixed conifer/pinegrass community had considerably fewer seedlings; some plots were understocked. Much of the understocking appeared to be related to low and irregular overstory density, lack of advance reproduction, reproduction destroyed by logging, and heavy grass cover.

Keywords: Regeneration (stand), partial cutting, regeneration (artificial), regeneration (natural), mixed stands, Blue Mountains (Oregon), Blue Mountains (Washington).

Research Summary

Regeneration of partial cuts in mixed conifer forests at midelevation in the Blue Mountains of northeastern Oregon and southeastern Washington was surveyed to determine the status of reforestation and to identify key environmental factors influencing establishment of seedlings. Plots were randomly located in partial cut units harvested during the 1970-76 period in the mixed conifer/pinegrass and grand fir/big huckleberry plant communities.

On the average, partial cuts in the grand fir community were well stocked with about 2,200 seedlings or saplings per acre (all origins); whereas partial cuts in the mixed conifer community had considerably fewer seedlings or saplings (761 per acre), and some plots were understocked. About 77 percent of the seedlings in the grand fir type and 57 percent in the mixed conifer type were of natural postharvest origin. Planted seedlings made up only 6 percent of the seedlings in the grand fir type but accounted for 20 percent of the regeneration in the mixed conifer type where overall seedling density was less. Planted seedlings were dominant on more of the plots than their small numbers might suggest because of their greater height and good distribution.

Greater stocking was generally associated with increasing density of the overstory, but a heavy grass cover had a negative effect on establishment of seedlings. Other factors, such as aspect, slope, and elevation, had a positive or negative effect on stocking, depending on the species and community. Understocking also appeared to be related to low and irregular overstory density, lack of advance reproduction, or reproduction destroyed by logging, and heavy grass cover.

Usually, residual stand density after the seed cut should be reduced to the minimum level at which an acceptable amount of regeneration will be obtained. It appears that about 30 square feet of basal area per acre in the grand fir type and 50 square feet in the mixed conifer type distributed uniformly over the area should result in adequate stocking in most units. The disturbance to the forest floor from logging and slash disposal operations is sufficient to break up heavy, compact layers of litter and duff and to expose enough mineral soil to prepare a suitable seedbed. An exception may be in areas of continuous heavy pinegrass sod where additional site preparation may be needed.

Planting after the seed cut is primarily needed in the mixed conifer/pinegrass community to insure the establishment of regeneration before seedbeds are occupied by pinegrass or other seeded grasses. In the grand fir/big huckleberry type, where natural regeneration is more abundant and certain, planting may be needed as a supplemental practice to replace natural regeneration destroyed or damaged during the final overstory removal.

Blowdown of the residual overstory was about the same in both communities—0.3 to 0.4 tree per acre. The risk of blowdown can be reduced by marking leave trees that are fully crowned dominants or codominants (the most windfirm and also the best producers of seed) and by locating cutting boundaries where the risk of windthrow is low.

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Introduction

During the early 1970's, many mixed conifer stands in the Blue Mountains of northeastern Oregon and southeastern Washington containing Rocky Mountain Douglas-fir and grand fir suffered mortality and damage from a severe outbreak of the Douglas-fir tussock moth.[1/] Dead and damaged trees on many of these areas were salvaged, and natural and planted regeneration has since developed in some of these partial cuts. The availability of these partial cuts on a variety of sites provided an opportunity to evaluate the status of the regeneration and the factors affecting its establishment. The units sampled in a study conducted in 1980 and 1981 on the Umatilla and Wallowa-Whitman National Forests, are referred to as partial cuts rather than shelterwoods because in most of the units attacks by the tussock moth resulted in a patchy distribution of surviving overstory. The remaining trees also consisted of a variety of sizes and qualities, rather than only the best fully crowned trees that would be left in a planned shelterwood. This paper reports the results of that study.

[1/] Scientific names are listed on page 14.

Objectives

The purposes of this study were to: (1) quantitatively evaluate the regeneration found on the partial cut units, (2) evaluate the condition of the residual overstory during the regeneration period, and (3) identify environmental factors associated with the presence or absence of regeneration. Specific objectives were to estimate: (1) success of regeneration in terms of stocking percentage and density (number per acre); (2) species composition of the regeneration; (3) stocking of regeneration of preharvest (advance) and postharvest (natural and planted) origin; (4) the relationship between regeneration and some measurable environmental variables, such as elevation, aspect, slope, and overstory density; and (5) survival and condition of the residual overstories.

Study Areas

Study areas (plots) were located in forests at midelevations of the Blue Mountains of northeastern Oregon and of southeastern Washington in the Umatilla and Wallowa-Whitman National Forests (fig. 1). Hall (1973) identified forest communities that occur in the study area or are similar. Identification of these plant communities is based on the dominant tree overstory and on shrubs, forbs, and grasses in the understory. Plots were located in two of these plant communities: (1) the mixed conifer/pinegrass community and (2) the grand fir/big huckleberry community. Being relatively stable, these plant communities can be placed within the habitat type classification, which stratifies environment by focusing on potential climax species. The mixed conifer/pinegrass community relates to at least three habitat types described for Idaho forest land: Douglas-fir/pinegrass (Daubenmire and Daubenmire 1968, Steele and others 1981), grand fir/pinegrass, and grand fir/white spirea (Steele and others 1981). Similarly, part of the grand fir/big huckleberry community type occurs on grand fir/blue huckleberry habitat types (Steele and others 1981).

The major tree species found in the mixed conifer/pinegrass community are ponderosa pine and Douglas-fir as seral species and grand fir as the climax species. In the grand fir/big huckleberry community, grand fir is the major tree species. If the site is moist enough, quantities of Engelmann spruce are present. Seral trees are ponderosa pine, Douglas-fir, and—depending on prior fire conditions—western larch and lodgepole pine.

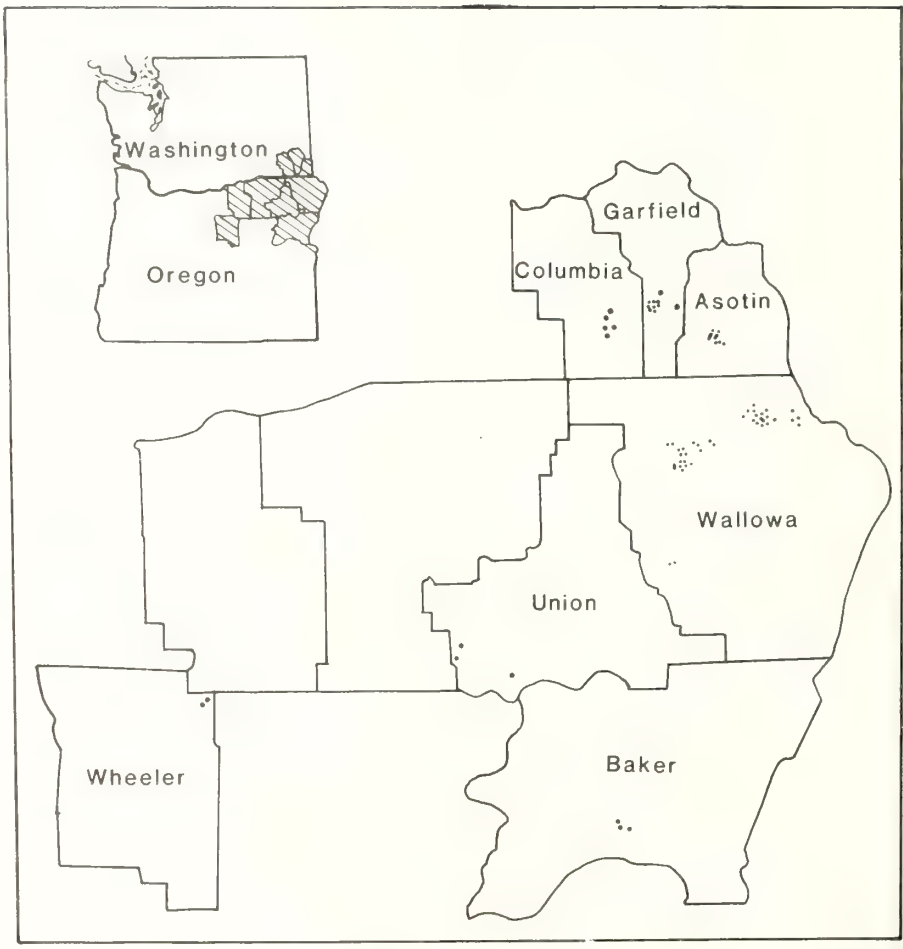

Figure 1.—Location of study areas in Oregon and Washington; one or two 10-acre plots were sampled in the vicinity of each dot.

Principal understory species of the mixed conifer/pinegrass community are common snowberry, white spirea, pinegrass, and elk sedge. Pinegrass often develops a more or less dense sod beneath the trees. Principal understory species of the grand fir/big huckleberry community are: big huckleberry, Utah honeysuckle, piper anemone, heartleaf arnica, wood strawberry, mountain sweet-root, and western meadowrue.

Predominant soils in these plant communities are immature Regosols (Vitrandepts) developed in the ash layer deposited from Mount Mazama or Glacier Peak. These are well-drained soils with silt loam A-C horizons over older buried soils or basalt (Wade 1975).

Some characteristics of the partial cuts sampled are given in table 1. In both plant communities, the residual overstory was similar in number of trees, basal area per acre, and average diameter. The major difference in the overstory between the two plant communities was species composition. In the mixed conifer/pinegrass community, 22 percent of the overstory was grand fir, 20 percent Douglas-fir, 43 percent ponderosa pine, 13 percent western larch, 2 percent lodgepole pine, plus a few Engelmann spruce. In the grand fir/big huckleberry community, there was considerably more grand fir (54 percent) and Engelmann spruce (16 percent) and fewer ponderosa pine (7 percent). In 61 partial cut units, slash was piled by machine and burned; in 14 units, it was not treated.

Table 1—Mean and range of some characteristics of partial cut units sampled in 2 plant communities in the Blue Mountains of northeastern Oregon and southeastern Washington

Characteristic	Unit of measure	Mixed conifer/pinegrass (38 plots)		Grand fir/big huckleberry (37 plots)	
		Mean	Range	Mean	Range
Elevation	Feet	4,780	4,200-5,300	4,874	4,200-5,400
Slope	Percent	5.1	0- 24	5.5	0- 16
Age	Years	5.7	4- 7	6.4	4- 12
Residual overstory:					
Trees per acre	Number	12.0	5- 31	14.0	3- 31
Average diameter	Inches	20.4	14.1- 25.3	19.4	13.9- 27.1
Basal Area	Square Feet	34.2	16- 67	33.4	7- 75
Crown closure	Percent	28.9	8- 54	26.9	8- 58
Seedbed: 1/					
Mineral soil	Percent	11.0	0- 44	9.0	0- 21
Litter	Percent	33.0	4- 72	41.0	4- 70
Slash	Percent	14.0	3- 30	14.0	8- 27
Litter and slash	Percent	38.0	13- 73	33.0	12- 62
Understory vegetation:					
Forbs	Percent	25.0	2- 49	15.0	0- 45
Shrubs	Percent	10.0	0- 37	10.0	0- 46
Grasses and sedges	Percent	28.0	2- 60	23.0	2- 62

1/ Total of all seedbed categories do not add to 100 percent because areas of some milacre plots are occupied by rocks and stumps.

Survey Design and Plot Selection

The mixed conifer and grand fir plant communities were considered separate populations. A record of units partially cut in 1976 or earlier in the two communities was obtained from the USDA Forest Service Regional Office (Pacific Northwest Region) in Portland, Oregon. Only units at least 4 years old were considered suitable for sampling so that reproduction would have had time to become established. The sampling unit was a square plot 10 acres in size. The total number of 10-acre plots in each plant community was then determined. In the mixed conifer community, 514 plots were available for sampling and 271 in the grand fir community.

We estimated that a total of about 75 plots could be sampled during the available time. Therefore, 38 plots were selected at random from the total number in the mixed conifer community and 37 from the total in the grand fir community. This resulted in a sampling intensity of about 7 and 14 percent, respectively. Candidate sample plots were rejected if the partial cut was seeded to trees or if it had been converted to nonforest uses.

Data Collection

A grid of 25 sample points (subplots) was centrally located on each 10-acre plot. Circular subplots (quadrats) were systematically spaced at 66-foot intervals on five parallel lines 66 feet apart containing five subplots each. At each of the 25 sample point locations in the plot, three concentric subplots (1-milacre, 4-milacre, and 0.0785-acre) were examined for presence of regeneration, associated environmental variables, and condition of residual overstory.

Information about the partial cut and the timber stand in which it was located was obtained from Ranger District records and from field observations. Information obtained was the plant community in which the plot was located; average elevation of the plot; timber type; date of harvest; slash treatment method and year of treatment; species planted and year of planting; subsequent cultural treatments; and general notes on size, growth, and distribution of regeneration, or damage. The plant community was verified by observation of adjacent uncut stands.

On each 1-milacre subplot, the total number of seedlings of each species was counted and recorded by origin. Regeneration was classified as of preharvest (advance) origin or of postharvest origin. Trees of postharvest origin were divided into 1- and 2-year-old seedlings from natural seed fall, seedlings 3 years old and older from natural seed fall, and planted trees. On each 4-milacre subplot, the species and origin (advance, natural postharvest, or planted) of the seedling most likely to dominate the subplot because of its size and vigor were recorded. Four-milacre subplots were used for data on dominant seedlings to reduce the probability of unstocked subplots. On each 0.0785-acre subplot, the species and diameter at breast height (d.b.h.) of all standing overstory trees, including trees that died during the regeneration period, were recorded plus the species, number, and d.b.h. of windthrown trees.

Planted trees were identified from information on species planted, date of planting, and spacing. In partial cuts where survival was high, regular rows of planted trees were clearly visible. Identification of planted trees was less certain when survival was low, but a count of whorls to check the age of a tree helped to identify planted trees.

The following environmental factors associated with each 1-milacre subplot were observed and recorded:[2/] aspect, slope, condition of the seedbed (mineral soil, litter, slash), degree of burn, understory vegetation (forbs, shrubs, grasses), residual overstory density (basal area and percent crown closure), and presence or absence of animal damage.

Data Analysis

To illustrate the present status of reforestation, we summarized data in tables showing seedling numbers and stocking percentage of milacre subplots by species and origin for the plant communities. To determine the relationship between regeneration and environmental variables, we used stepwise multiple regression procedures to fit linear equations of the form $Y = b_0 + b_1X_1 + b_2X_2 + \ldots b_nX_n$ to the data. Dependent (Y) variables used were percentages of milacre subplots stocked and number of seedings per acre of the various species and origins, and the independent (X) variables were the environmental variables given in the appendix.[3/] Curvilinear equations of the form $Y = a + b(1 - e^{-cX})^d$ were used to relate individual independent variables to percentage of stocked milacres because in some cases they described the relationship more realistically than did a linear model.

[2/] See appendix for details of procedures for measuring and coding the environmental factors.

[3/] Subplots were considered stocked if they contained at least one seedling.

Regeneration Stocking and Density

Based on average seedling numbers and percentage of stocked milacres for all species and origins combined, regeneration was generally adequate in both plant communities. Plots in the grand fir/big huckleberry community averaged 2,201 seedlings per acre (all classes) compared with 761 in the mixed conifer/pinegrass community (table 2). About 50 percent of the milacre subplots were stocked with a seedling of any origin or species in the grand fir type and 37 percent in the mixed conifer type.

The majority of the seedlings in both communities became established after logging and were of natural origin (57 percent in the mixed conifer type and 77 percent in the grand fir type). Advance reproduction also was an important part of the regeneration, comprising about one-fifth of the total number of seedlings in each community. Distribution of advance reproduction was clumpy, occurring primarily in small areas undisturbed by logging activity.

One- and two-year-old seedlings also made up about one-fifth of the regeneration but, because of their small size and high mortality rate, are less important in overall regeneration than advance reproduction. The effect of these young seedlings was primarily to increase density of the regeneration rather than to greatly raise stocking percentages. For example, in the grand fir community, 1-and 2-year-old seedlings were the second largest group (511 per acre) (table 2), but stocking was increased more than 12 percent on only two of the 37 plots. Planted seedlings made up only 5 percent of all regeneration in the grand fir type but accounted for 19 percent of the seedlings in the mixed conifer community because there were fewer seedlings of other origins. Although there were relatively few planted seedlings, their uniform distribution resulted in a greater percentage of stocked milacres than might be expected by their small numbers (table 2).

The largest single component of the regeneration is natural postharvest seedlings 3 years and older (table 2). Because these partial cut units are only 5 to 6 years old, adequate seed fall must have occurred within 1 to 3 years after

Table 2—Average stocking percent and number of seedlings per acre of all species in 2 plant communities on partial cut units in the Blue Mountains of northeastern Oregon and southeastern Washington, by class of reproduction [1]

Class of regeneration	Mixed conifer/pinegrass			Grand fir/big huckleberry		
	Number of plots	Mean ± S.E. [2]	Range	Number of plots	Mean ± S.E. [2]	Range
		Stocking Percent				
Advance	38	11.3 ± 2.2	0- 60	37	16.3 ± 2.2	0- 48
Postharvest:						
1- and 2-year-old seedlings	38	6.7 ± 1.6	0- 48	37	14.6 ± 2.6	0- 68
3-year-old and older seedlings	38	14.5 ± 2.3	0- 52	37	28.8 ± 3.8	0- 92
Planted seedlings	35	13.7 ± 2.2	0- 36	35	11.4 ± 1.6	0- 36
All classes except 1- and 2-year-old seedlings	38	34.0 ± 3.2	0- 72	37	45.7 ± 3.7	8- 96
All classes	38	36.8 ± 3.4	4- 80	37	49.8 ± 3.7	12- 100
		Number of seedlings				
Advance	38	178 ± 43	0-1,120	37	378 ± 77	0- 2,000
Postharvest:						
1- and 2-year-old seedlings	38	120 ± 37	0-1,240	37	511 ± 187	0- 5,520
3-year-old and older seedlings	38	315 ± 71	0-1,160	37	1,192 ± 286	0- 7,800
Planted seedlings	35	148 ± 24	0- 400	35	120 ± 17	0- 360
All classes except 1- and 2-year-old seedlings	38	641 ± 98	0-2,920	37	1,691 ± 296	80- 8,280
All classes	38	761 ± 121	40-3,400	37	2,201 ± 448	120-12,800

1/ Based on 1-milacre subplots

2/ S.E. = standard error.

Table 3—Proportion of partial cut units stocked at various levels with 3-year-old and older advance and postharvest regeneration in 2 plant communities in the Blue Mountains of northeastern Oregon and southeastern Washington [1]

Community	Stocking			Trees per acre		
	At least	Plots	Proportion of total	At least	Plots	Proportion of total
	Percent	Number	Percent	Number	Number	Percent
Mixed conifer/pinegrass (38 plots)	20	29	0.76	200	30	0.79
	40	17	.45	400	23	.61
	60	4	.11	700	14	.37
	80	0	0	1,000	7	.18
				2,000	2	.05
				3,000	0	0
Grand fir/big huckleberry (37 plots)	20	34	.92	200	36	.97
	40	22	.59	400	30	.81
	60	11	.30	700	25	.68
	80	2	.05	1,000	19	.51
				2,000	12	.32
				3,000	6	.16

1/ Based on 1-milacre subplots.

logging for seedlings of this age to be present. The pattern of immediate establishment of natural regeneration after logging on most of these units is similar to that found on mixed conifer shelterwood units on the east slope of the Cascade Range (Seidel 1979b.). Because of the generally good seed production at frequent intervals in mixed conifer forests east of the Cascades, there is a good chance of obtaining a reasonable number of seedlings within a few years after logging.

Although the overall averages of seedling density and stocking indicate regeneration was generally successful, some units were not adequately stocked whereas others had a relative abundance of seedlings. For a clearer picture of the status of regeneration on these partial cuts, plots were grouped by the number and percentage that attained specific levels of stocking or density (table 3).

Depending on the definition of adequate stocking, the proportion of partial cuts successfully regenerated can be determined. For example, if 40-percent stocking of milacre quadrats is considered satisfactory, then only 45 percent of the mixed conifer/pinegrass units meet this standard compared with 59 percent of the grand fir/huckleberry units. On the basis of seedling density, 61 percent of the mixed conifer and 81 percent of the grand fir partial cuts had at least 400 seedlings per acre. Overstocking on these units was generally not a problem except on one plot in the grand fir type that had 12,800 seedlings per acre and two others that had more than 7,000 seedlings per acre.

Species Composition of Regeneration

Ponderosa pine, Douglas-fir, and grand fir were the three most common species in the mixed conifer/pinegrass type (table 4). The three major species in the grand fir community were grand fir, Engelmann spruce, and Douglas-fir. The primary difference in species composition between the two types was in the mixed conifer type; only a trace of Engelmann spruce occurred in the reproduction (0.3 percent), whereas in the grand fir type spruce was found on nearly 15 percent of the subplots.

Dominant Species

In addition to measurements of seedling stocking and density, from which the abundance and distribution of regeneration can be estimated, the species and origin of the largest or most vigorous seedling on each 4-milacre subplot were recorded. This gives an indication of the species most likely to predominate as the stand develops.

In the mixed conifer units, the three dominant species in the reproduction were ponderosa pine, Douglas-fir, and grand fir (table 5). Planted seedlings were dominant on 48 percent of the stocked subplots, and planted ponderosa pine was dominant on about 32 percent of the quadrats—the single largest species-origin combination. Advance reproduction was dominant on one-third of the stocked quadrats; it consisted primarily of grand fir and Douglas-fir.

In grand fir partial cuts, reproduction of natural postharvest origin was dominant on about 35 percent of the stocked quadrats compared with only 19 percent in the mixed conifer units (table 5). Advance reproduction dominated on 36 percent of the subplots, chiefly because of advance grand fir seedlings which were dominant on about 22 percent of the quadrats. In both these communities, planted seedlings assume greater importance as a stand component than their small numbers would suggest because of their uniform distribution.

Relation of Stocking and Density to Environmental Factors

The influence of observed environmental factors on regeneration and their relative importance in descriptions of present stocking and seedling density were determined by stepwise regression analyses. Some of the results of these analyses are presented in tables 6 and 7—the positive or negative relationship to stocking and density and the order in which variables appear in the equations.

It is apparent that the effect these variables have on stocking and density of regeneration depends on both the species and origin of reproduction and the plant community. For example, in the grand fir type aspect and elevation were positively related to reproduction, whereas in the mixed conifer community, there was little relationship (tables 6 and 7). The effect of most variables is logical and has a reasonable biological explanation.

Table 4—Average stocking of advance and postharvest regeneration on partial cut units in 2 plant communities in the Blue Mountains of northeastern Oregon and southeastern Washington, by species 1/

Community and regeneration	Grand fir	Douglas-fir	Western larch	Engelmann spruce	Ponderosa pine	Lodgepo pine
	Stocking percent ± S.E. 3/					
Mixed conifer/pinegrass:						
Advance regeneration	5.8 ± 1.3	2.7 ± 0.8	0.3 ± 0.2	0.1 ± 0.1	2.5 ± 1.1	1.5 ± 1.
Postharvest seedlings 2/--						
3-year-old and older	5.1 ± 1.4	8.1 ± 1.4	2.5 ± 1.0	0.2 ± 0.2	12.8 ± 1.7	2.2 ± 1.
1- and 2-year old	2.2 ± 0.7	2.4 ± 0.7	0.1 ± 0.1	0 ± --	1.6 ± 0.5	1.4 ± 0
All classes	11.2 ± 2.2	12.1 ± 1.8	3.1 ± 1.0	0.3 ± 0.3	15.8 ± 1.8	2.8 ± 1
Grand fir/big huckleberry:						
Advance regeneration	11.8 ± 1.8	1.0 ± 0.3	1.5 ± 0.7	3.4 ± 1.1	0.1 ± 0.1	0.5 ± 0.
Postharvest seedlings 2/--						
3-year-old and older	15.1 ± 3.2	10.1 ± 2.1	3.1 ± 0.8	9.3 ± 1.1	7.1 ± 1.5	4.0 ± 1.
1- and 2-year-old	7.0 ± 2.0	2.6 ± 0.8	1.1 ± 0.4	4.6 ± 1.5	1.1 ± 0.5	2.2 ± 1
All classes	26.6 ± 3.5	13.0 ± 2.5	5.4 ± 1.3	14.5 ± 2.4	8.1 ± 1.7	5.2 ± 2

1/ Based on 1-milacre subplots.

2/ Includes natural and planted regeneration.

3/ S.E. = standard error.

Table 5—Stocked subplots by species and origin of dominant seedlings in 2 plant communities on partial cut units in the Blue Mountains of northeastern Oregon and southeastern Washington 1/

Origin of seedlings	Grand fir	Douglas-fir	Western larch	Englemann spruce	Ponderosa pine	Lodgepole pine	Total
	Percent						
Mixed conifer/pinegrass:							
Advance	14.8	9.1	1.2	0.2	6.6	1.2	33.1
Natural postharvest	8.5	4.8	1.2	--	3.6	.5	18.6
Planted	.5	14.3	.8	--	32.4	.3	48.3
Total	23.8	28.2	3.2	.2	42.6	2.0	100.0
Grand fir/big huckleberry:							
Advance	21.6	1.9	2.5	8.2	.7	1.2	36.1
Natural postharvest	13.1	4.4	2.3	8.2	2.5	4.0	34.5
Planted	2.6	9.7	--	3.7	12.8	.6	29.4
Total	37.3	16.0	4.8	20.1	16.0	5.8	100.0

1/ Based on 4-milacre subplots; 1- and 2-year-old seedlings included.

Table 6—Positive and negative correlations of variables and the order in which they appeared in regression equations describing stocking of regeneration in 2 plant communities on partial cut units in the Blue Mountains of northeastern Oregon and southeastern Washington 1/

Species or origin	Aspect	Slope	Elevation	Mineral soil	Litter	Slash	Burn	Forbs	Shrubs	Grass	Basal area	Crown closure	Trees per acre	Quadratic mean diameter	Animal damage	Gopher activity	Age	R^2	Standard error of stocking percent
Grand fir/big huckleberry:																			
All regeneration	+6		+1	-2				+7	+3	-5				-4				0.71	12.5
All natural regeneration	+6	-2	+1	-3					+2	-5				-4				.78	10.9
3-year-old and older seedlings	+7		+1	-5			+8	+2	+4	-6				-3				.66	13.7
1- and 2-year-old seedlings		+2	+3		+4				+5				+1	-6	+8		-7	.73	6.6
Natural postharvest			+1	-6				+2	+4			+5		-3				.65	13.4
Postharvest grand fir	+4	+3								-1				-5	+2			.70	9.1
All grand fir	+2					+7	+6		+4	-1			-5		+3			.73	10.4
All Douglas-fir			+3					+2	+8	+5	-4	+1		+7	+6			.72	8.7
All larch	+4	-2	+6			+8		+1	+2			-7		+9			-5	.69	5.2
All spruce	+3		+1	-4	+2													.51	9.6
All ponderosa pine			-2	-1	-4		+3	-6		+5					+7			.47	8.2
Mixed conifer/pinegrass:																			
All regeneration									+1	-4		+2	-5		+3			.69	12.4
All natural regeneration						+4		-3	+2	-6		+1			+5			.79	10.3
3-year-old and older seedlings	-4			-5					+2	-3		+2	-6					.62	9.4
1- and 2-year-old seedlings					+6			-3	+2			+1		-4	-5			.42	8.3
Natural postharvest						+3		-6	+1	-5		+2		-4				.64	10.4
Postharvest grand fir	-5								+2	-3		+1					-4	.52	7.0
All grand fir								-7		-6	+4	+1	-2		+5	-3	-8	.72	7.9
Postharvest Douglas-fir					+4			+3		-1			+2					.23	8.7
All Douglas-fir				-5	+3			+2				+1					+4	.30	10.2
All larch			-5						+1	-2	-3			+4				.59	4.1
All ponderosa pine		+3	-5							-2	-4				+1			.74	6.3

1/ Numbers indicate the order in which variables entered the regression equation. Only variables that accounted for the major portion of the variation in stocking percent are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

Table 7—Positive and negative correlations of variables and the order in which they appeared in regression equations describing density of regeneration in 2 plant communities on partial cut units in the Blue Mountains of northeastern Oregon and southeastern Washington 1/

Species or origin	Aspect	Slope	Elevation	Mineral soil	Litter	Slash	Burn	Forbs	Shrubs	Grass	Basal area	Crown closure	Trees per acre	Quadratic mean diameter	Animal damage	Gopher activity	Age	R^2	Standard error of seedling density
Grand fir/big huckleberry:																			
All regeneration	+6		+1	-4	+7			+8	+2	-5				-3				0.69	947
All natural regeneration	+6		+1	-4	+7				+2	-5				-3				.67	953
3-year-old and older seedlings	+7		+1	-5			-4		+3	-6				-2				.53	939
1- and 2-year-old seedlings		+2	+4		+3			+5		-6			+1					.63	206
Natural postharvest	+6		+1				-4		+3	-5				-2				.56	1013
Postharvest grand fir	+4	+2								-3			-6		+1		-5	.52	452
All grand fir	+2									-1			-4		+3		-5	.50	577
All Douglas-fir			+3				+5	+2		+4		+1						.57	172
All larch		-3	+8			+10		+2	+1	+5		-9	+4	+6			-7	.69	68
All spruce	+6		+5		+3								+2			-4	+1	.37	1016
All ponderosa pine			-3	-2	-4		+1											.56	115
Mixed conifer/pinegrass:																			
All regeneration									+2		+6	+1	-5	-4	+3			.65	483
All natural regeneration						+4		-3	+2	-5	+1							.63	504
3-year-old and older seedlings					-6	+2	-4				+1				+5	-3		.56	316
1- and 2-year-old seedlings		+3	-2									+1		-4	-5			.42	184
Natural postharvest						+4			+2			+1		-3				.50	436
Postharvest grand fir						+3						+1				-2		.40	252
All grand fir											+5	+1	-4	-3			-2	.53	311
Postharvest Douglas-fir								+2				+1	+3					.28	145
All Douglas-fir		+3						+2				+1						.33	164
All larch			-2						+1	-3	-5			+4				.63	42
All ponderosa pine									+3				+2		+1			.58	244

1/ Numbers indicate the order in which variables entered the regression equation. Only variables that accounted for the major portion of the variation in density of seedlings are given. Variables were excluded if they failed to raise R^2 values by at least 3 percent.

Exceptions are the negative correlation of mineral soil to regeneration in the grand fir type and the positive correlation of animal damage to regeneration in both communities. The negative correlation of mineral soil to regeneration was not expected because studies have shown mineral soil to be the most favorable seedbed for natural regeneration (Seidel and Cooley 1974, Seidel 1979a). Although mineral soil is an excellent seedbed for natural regeneration, many seedlings (especially true fir) do become established in light to medium litter layers (one-fourth to one-half inch deep). Also, light amounts of slash provide a favorable environment for seedling establishment because of the protection offered against temperature extremes. Therefore, it is neither necessary nor desirable to completely remove all litter and slash from the seedbed. Generally, enough disturbance is caused by logging and slash disposal to provide a receptive seedbed, except possibly in areas of continuous heavy pinegrass sod. A positive correlation of animal damage and regeneration also was not expected, although disturbance as a result of livestock and big game activity may have resulted in a more favorable seedbed. Consumption of understory vegetation (especially grass) by animals could also reduce competition for water and nutrients and thus increase survival of seedlings.

Similar to stocking in shelterwood units in the Cascade Range, stocking of regeneration decreased as grass cover increased in both plant communities (fig. 2). Although the equations relating milacre stocking to grass cover were highly significant ($P<0.01$) for both communities, there was still too much unexplained variation for use as prediction equations. The equations do indicate, however, that heavy amounts of grass can reduce the chance of successful establishment of tree seedlings.

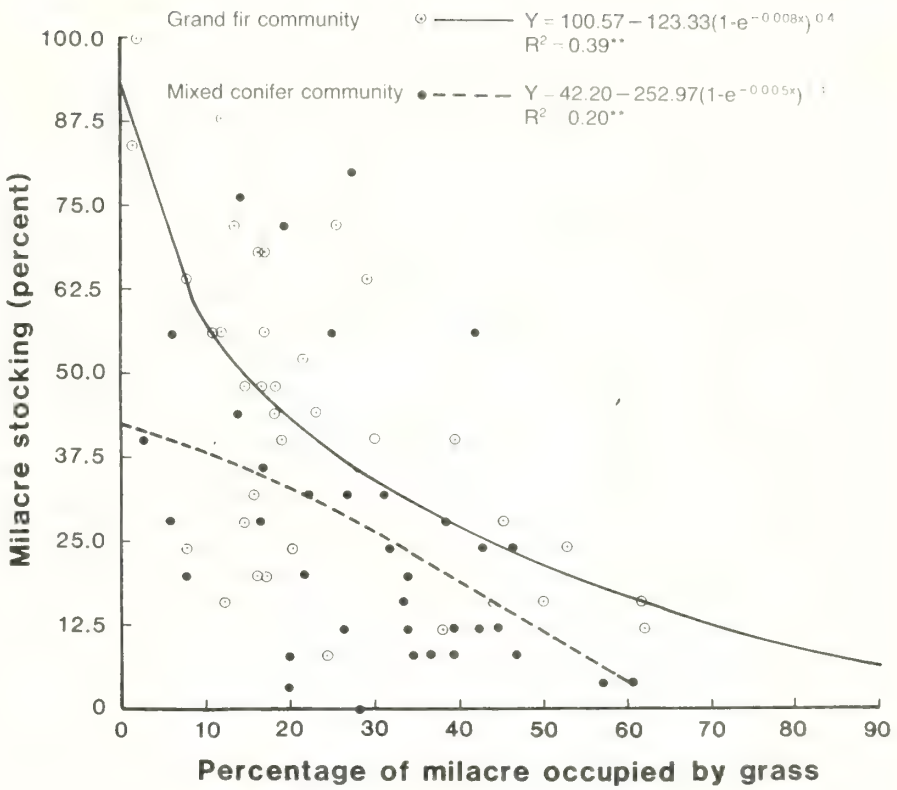

Figure 2.—Relationship between amount of grass cover and milacre stocking of natural regeneration in the grand fir and mixed conifer plant communities in the Blue Mountains of northeastern Oregon and southeastern Washington; ** = significant at the 1-percent level.

Residual Stand Density and Regeneration

Both basal area and crown closure were positively correlated with density and stocking of natural regeneration, especially in the mixed conifer/pinegrass community where crown closure entered as the first or second variable in nearly all the equations (tables 6 and 7).

The equations describing the relationship of basal area or overstory crown closure to stocking of natural regeneration, although highly significant ($P<0.01$), are not accurate enough to be used as predictors of expected regeneration (figs. 3 and 4). In addition, these equations were not tested against an independent set of data. They do, however, give some idea of the general trend of reproduction as stand density varies and the range of stand densities where successful natural regeneration can be expected.

Overstory crown closure was better correlated with milacre stocking (fig. 4) than was basal area (fig. 3), and for both density measures the relationship was stronger in the mixed conifer/pinegrass community.

In both plant communities, stocking of milacres increased as stand density increased, and there was a large amount of unexplained variation in stocking. At lower density levels (less than 56 square feet of basal area per acre or 50-percent crown closure), milacre stocking was greater in the grand fir/big huckleberry type than in the mixed conifer/pinegrass type for a given level of stand density (figs. 3 and 4). In general, residual stand density after the seed cut should be reduced to the minimum level at which an acceptable amount of regeneration will be obtained. Because of the large amount of unexplained variation associated with these equations, they should be used only as crude indicators of possible desirable stand density levels. From the data obtained from these partial cuts, it appears that if at least 40-percent stocking of milacre plots is desired, then a basal area of about 30 square feet per acre in the grand fir/big huckleberry type and about 50 square feet per acre in the mixed conifer/pinegrass type should result in adequate stocking on most units. Data from a shelterwood study on the Starkey Experimental Forest in eastern Oregon suggest that adequate natural regeneration can be obtained from lower stand densities if fully crowned dominant and codominant seed trees are distributed uniformly over the area.[4/]

[4/] Data on file at Silviculture Laboratory, Bend, Oregon

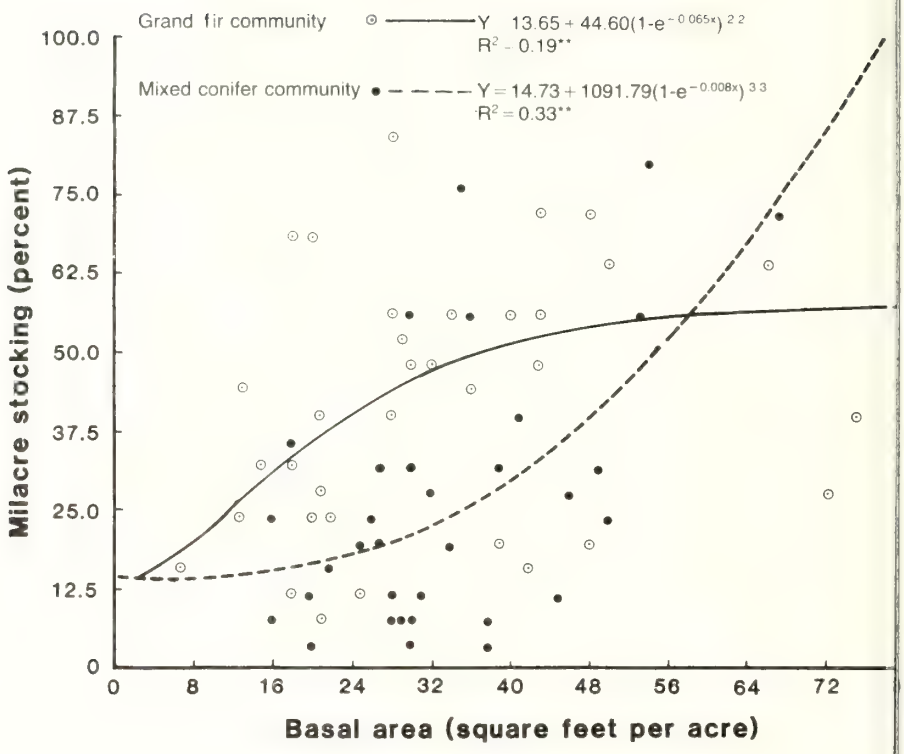

Figure 3.—Relationship between basal area and milacre stocking of natural regeneration in the grand fir and mixed conifer plant communities in the Blue Mountains of northeastern Oregon and southeastern Washington; ** = significant at the 1-percent level.

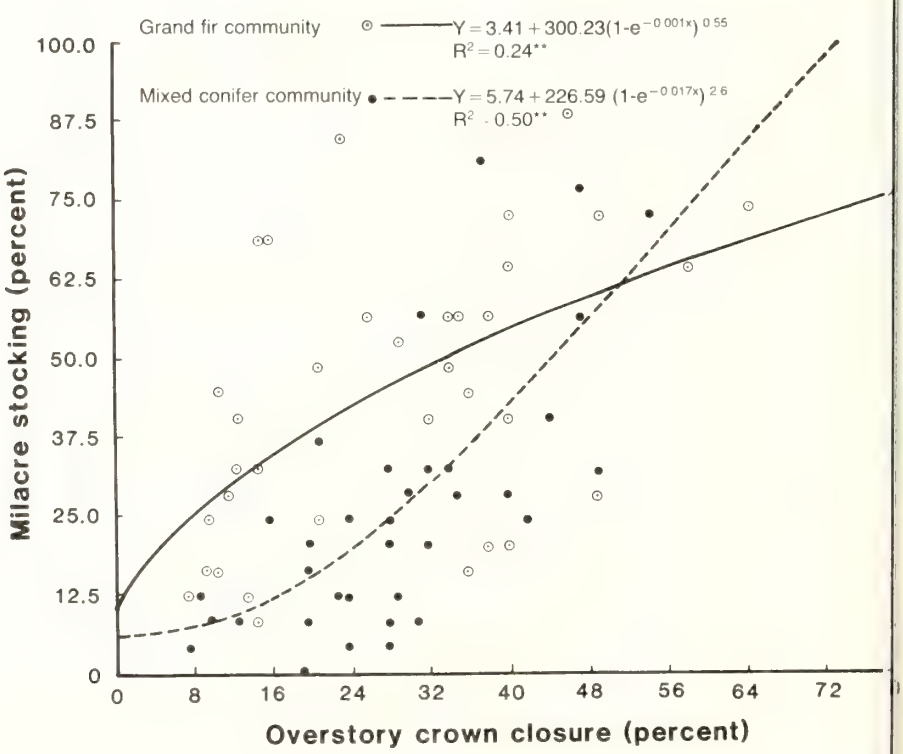

Figure 4.—Relationship between overstory crown closure and milacre stocking of natural regeneration in the grand fir and mixed conifer plant communities in the Blue Mountains of northeastern Oregon and southeastern Washington; ** = significant at the 1-percent level.

Impact of Planted Seedlings

Planted seedlings are of greater importance for regeneration in units where natural reproduction is light. Planted seedlings made up only 5 percent of the total number of seedlings in the grand fir community compared with 19 percent in the mixed conifer type where natural regeneration was not as abundant.

As discussed previously, however, because of their good distribution planted seedlings contribute more than their small numbers might suggest. If a unit is considered adequately stocked when 40 percent of the milacre quadrats contain at least one seedling, then planting increased the stocking above this level on only 3 percent of the grand fir/big huckleberry units compared with 24 percent of the mixed conifer/pinegrass units.

The results of this study show that the need for planting depends on the plant community and other factors such as how rapidly understory vegetation occupies disturbed areas. The most likely candidates for planting immediately after the seed cut are shelterwood units in mixed conifer/pinegrass communities where there is a good chance of the seedbed being occupied by pinegrass and other vegetation before natural tree seedlings have had a chance to become established. On many of these units, both planted and natural seedlings are subject to severe competition not only from pinegrass but also from direct seeded grasses such as timothy and orchardgrass. On the other hand, in grand fir/big huckleberry types, especially on north slopes, where abundant natural regeneration is likely to occur, the most efficient use of planting is to increase stocking if removal of the residual overstory has reduced stocking below minimum standards.

The species planted should be native to the plant community. In the mixed conifer/pinegrass type, ponderosa pine and Douglas-fir are good species to plant. Douglas-fir is suitable for north and east slopes, whereas ponderosa pine should be favored on warmer south and west aspects. In the grand fir/huckleberry types, consideration should also be given to planting grand fir and Engelmann spruce—especially on higher elevation north to east slopes where these species naturally occur.

Overstory Mortality

Mortality of the residual overstory after partial cutting was about the same in both communities. In the grand fir type, about 16 percent of the overstory was lost—an average of 0.4 tree per acre blown down and 1.8 tree per acre standing dead. In the mixed conifer community, 13 percent of the trees were lost—0.3 tree per acre to windthrow and 1.3 per acre standing dead.

Blowdown can be a problem when the shelterwood system is used or partial cuts are made in unmanaged old-growth stands because trees growing at high densities have not developed the windfirmness needed to resist greater stresses from wind after heavy partial cuts. The risk of blowdown can be reduced by leaving dominant or codominant, full-crowned trees which are the most windfirm and also the best seed producers (Gordon 1973). In addition, use of guidelines for locating cutting boundaries and for identifying topographic situations where the risk of blowdown is high can decrease the mortality from windthrow. Alexander (1964) has prepared guidelines for spruce-fir forests in Colorado that may be useful in the high elevation mixed conifer forests of eastern Oregon and Washington.

The results of this study indicate that a combination of advance reproduction, natural regeneration, and planted seedlings generally resulted in satisfactory stocking on most of the partial cut units. Regeneration was usually abundant in the grand fir/big huckleberry community, because of many grand fir, Douglas-fir, and Engelmann spruce seedlings of natural origin. Most of the understocked units were in the mixed conifer/pinegrass community and appeared to be related to at least one of the following factors: low and irregular overstory density, lack of advance reproduction or reproduction destroyed in logging, and heavy grass cover.

Using the shelterwood system where the residual overstory is composed of healthy dominant and codominant trees spaced uniformly over the area should result in adequate numbers of natural seedlings if a basal area of about 30 square feet per acre is left in the grand fir type and about 50 square feet per acre in the mixed conifer type. Where problems with animal damage to natural or planted regeneration are expected, an effort should be made to save as much of the advance reproduction as possible if it is sufficiently vigorous to respond to release. Even though suppressed for many years, vigorous, full-crowned trees will respond to release (Seidel 1977). Saving the advance reproduction or established regeneration requires good coordination between timber and fuels management staffs and the skillful application of logging techniques designed to preserve the established reproduction such as those suggested by Gottfried and Jones (1975).

Planting is needed after partial cutting or when the shelterwood system is used, primarily in the mixed conifer/pinegrass community to insure the establishment of regeneration before seedbeds are occupied by grass and other vegetation. Often cutting units were seeded immediately to orchardgrass, timothy, or

other introduced grasses which, together with the native vegetation, can inhibit or exclude natural tree regeneration. In the grand fir/big huckleberry type, where natural regeneration is more abundant and certain, planting seems best suited as a supplemental practice to replace natural regeneration destroyed or damaged during the final overstory removal. Planting is not needed in units that are already fully stocked or overstocked with natural regeneration. Ponderosa pine and Douglas-fir are the preferred species to plant in these communities, but they should not be planted on sites where, because of snow and ice or soil conditions, the logical species to plant are the naturally occurring grand fir or Engelmann spruce. Such cold and moist sites are indicated by the abundant seedlings and saplings of these species already present.

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot/acre = 0.2296 square meter/hectare
1 tree/acre = 2.47 trees/hectare

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Independent (X) variables used in regression analyses:

1. Elevation.—The average elevation of the plot to the nearest 10 feet as measured with an altimeter.

2. Aspect.—One of eight compass points measured on each subplot. The method proposed by Day and Monk (1974) was used to code the aspect, and the following values were assigned to compass directions: N - 14; NE - 15; E - 11; Se - 7; S - 3; SW - 2; W - 6; NW - 10. Average coded value of the 25 subplots was used in analyses.

3. Slope.—Percentage slope of each subplot was measured with a clinometer and coded as follows: 0-9 percent, 0; 10-19 percent, 1; 20-29 percent, 2; 30-39 percent, 3; etc. Average coded value of subplots was used.

4. Mineral soil.—The percentage of each subplot containing mineral soil was estimated, coded in the same way as slope values, and averaged.

5. Litter.—The percentage of each subplot covered with litter was estimated, coded in the same way as slope values, and averaged.

6. Slash.—The percentage of each subplot covered with slash was estimated, coded in the same way as slope values, and averaged.

7. Degree of burn.—Estimated on each subplot and coded as: None, 0; light, 1; medium, 2; heavy, 3. Averaged coded value was used in analyses. Degree of burn is defined as: None—no visible effect of fire; light—fire charred the surface of the forest floor but did not remove all the litter layer; medium—fire removed all the litter layer and some of the duff; heavy—fire removed all the litter and duff and imparted a color to the mineral soil.

8. Forbs.—The percentage of each subplot covered with forbs was estimated, coded in the same way as slope values, and averaged.

9. Shrubs.—The percentage of each subplot covered with shrubs was estimated, coded in the same way as slope values, and averaged.

10. Grasses and sedges.—The percentage of each subplot covered with grasses and sedges was estimated, coded in the same way as slope values, and averaged.

11. Basal area.—The overstory basal area at each subplot was measured with a 10- factor angle gage and averaged for use in analyses.

12. Crown closure.—The overstory crown closure was measured with a spherical densiometer at each subplot by Strickler's (1959) method. Average value of the 25 subplots was used in analyses.

13. Overstory trees per acre.—The numbers of standing overstory trees (living and dead) and blown down trees were recorded on 0.0785-acre subplots at each of the 25 sample points, averaged, and converted to a per-acre basis.

14. Overstory average diameter.—The diameters at breast height of living and dead standing trees and blown down trees on each 0.0785-acre subplot were measured to the nearest inch and averaged.

15. Animal damage.—The presence or absence of damage such as browsing or trampling by animals other than gophers (primarily deer, elk, or cattle) was recorded for each subplot. The percentage of subplots showing such damage was used in the analyses.

16. Gopher activity.—The presence or absence of gopher activity as indicated by mounds was recorded for each subplot. The percentage of subplots showing such activity was used in the analyses.

Common and Scientific Names [5/]

Plants

Trees:	
Douglas-fir (Rocky Mountain)	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Western larch	*Larix occidentalis* Nutt.
Shrubs:	
Big huckleberry	*Vaccinium membranaceum* Dougl. ex Hook.
Blue huckleberry	*Vaccinium globulare* Rydb.
Common snowberry	*Symphoricarpos albus* (L.) Blake
Utah honeysuckle	*Lonicera utahensis* Wats.
White spirea	*Spiraea betulifolia* Pall.
Forbs:	
Heartleaf arnica	*Arnica cordifolia* Hook.
Mountain sweet-root	*Osmorhiza chilensis* H. & A.
Piper anemone	*Anemone piperi* Britt.
Western meadowrue	*Thalictrum occidentale* Gray
Wood strawberry	*Fragaria vesca* var. *bracteata* (Heller) Davis
Grasses and sedges:	
Elk sedge	*Carex geyeri* Boott
Orchardgrass	*Dactylis glomerata* L.
Pinegrass	*Calamagrostis rubescens* Buckl.
Timothy	*Phleum pratense* L.

Insect

Douglas-fir tussock moth	*Orgyia pseudotsugata* (McDunnough)

[5/] Sources for nomenclature: trees—Little (1979); shrubs, forbs, and grasses and sedges—Garrison and others (1976); and insects—Furniss and Carolin (1977).

Seidel, K. W.; Head, S. Conrade. Regeneration in mixed conifer partial cuttings in the Blue Mountains of Oregon and Washington. Res. Pap. PNW-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983**. 14 p.

A survey in the Blue Mountains of northeastern Oregon and southeastern Washington showed that, on the average, partial cuts in the grand fir/big huckleberry community were well stocked with a mixture of advance, natural postharvest, and planted reproduction of a number of species. Partial cuts in the mixed conifer/pinegrass community had considerably fewer seedlings; some plots were understocked. Much of the understocking appeared to be related to low and irregular overstory density, lack of advance reproduction, reproduction destroyed by logging, and heavy grass cover.

Keywords: Regeneration (stand), partial cutting, regeneration (artificial), regeneration (natural), mixed stands, Blue Mountains (Oregon), Blue Mountains (Washington).

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Growth of Ponderosa Pine Poles Thinned to Different Stocking Levels in Central Oregon

James W. Barrett

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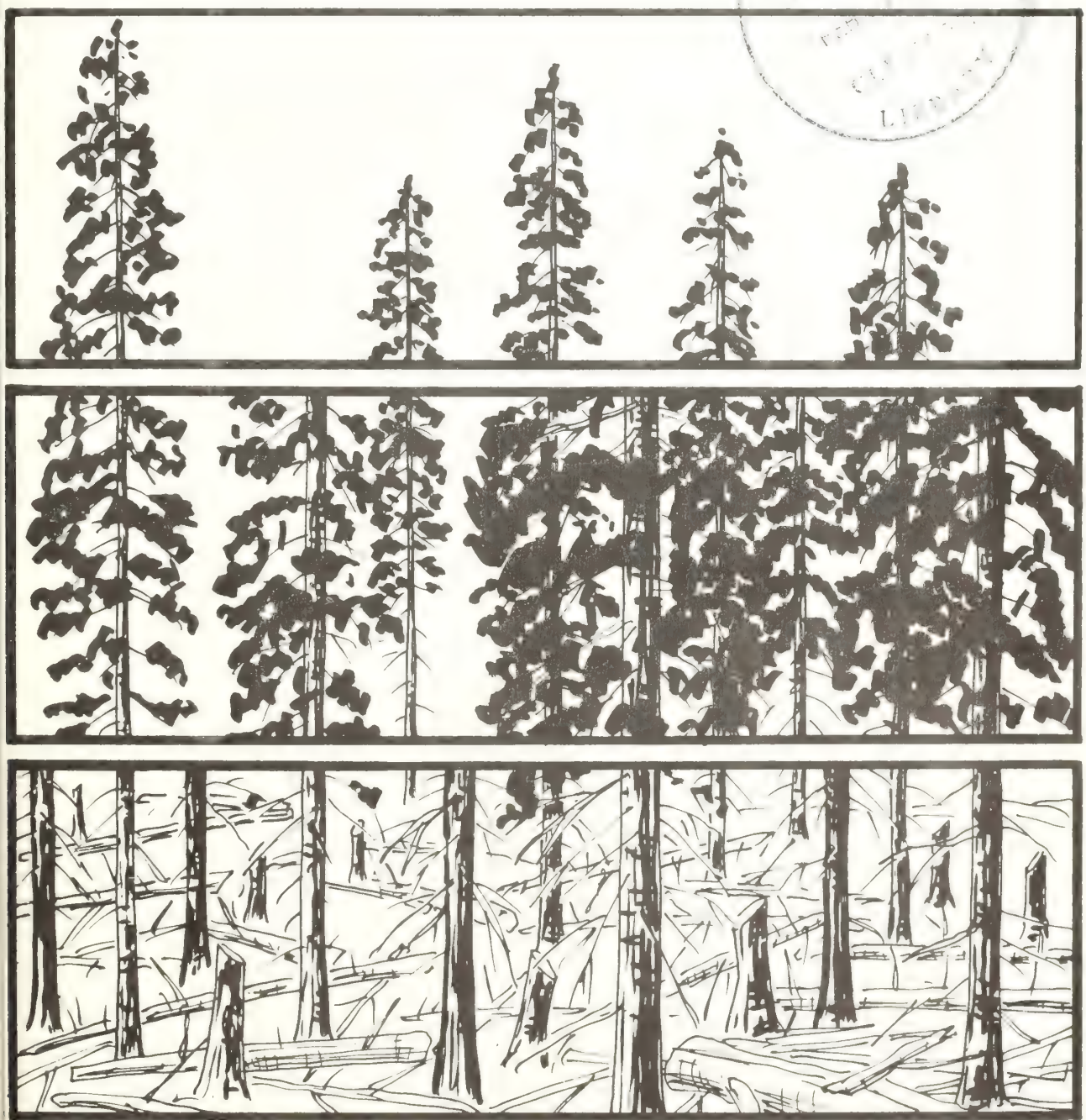

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Abstract

Barrett, James W. Growth of ponderosa pine poles thinned to different stocking levels in central Oregon. Res. Pap. PNW-311. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 9 p.

This paper presents 15-year results of one installation of a west-wide study of growing-stock levels in even-aged ponderosa pine. Growth was related to growing-stock level in a 65-year-old pole stand on an above average site. Periodic growth is presented for 10 years after the initial thinning and for 5 years after a second thinning to six assigned growing-stock levels.

Annual growth in diameter during the 5 years after initial thinning ranged from an average of about 0.28 inch at the lowest growing-stock level to 0.10 at the highest. These rates increased slightly during the following decade, but differences between growing-stock levels remained about the same. These growth relations resulted in much larger trees at the lower growing-stock levels 15 years after the initial thinning.

Keywords: Growing stock (-increment/yield, thinning effects, even-aged stands, improvement cutting, stand density, ponderosa pine, *Pinus ponderosa.*

Summary

Some of the most productive ponderosa pine stands in central Oregon are composed of densely stocked pole-size trees that are approaching merchantable size. These high densities should be reduced by thinning to concentrate the potential of the site to produce useful wood on trees that are merchantable or will soon reach merchantable size. In addition, evidence is mounting that reducing density will reduce the incidence of mountain pine beetle attack. Optimum stocking for these stands is the subject of this paper. The study, one of six initiated in the West, looked at the desirability of various growing-stock levels in a 65-year-old pole stand with above-average site index. Six growing-stock levels (GSL's)—basal areas anticipated when trees average 10 inches or more in diameter at breast height (d.b.h.)—ranging from 30 to 150 square feet per acre were tested.

Annual growth in diameter during the 5 years after initial thinning ranged from an average of about 0.28 inch at the lowest GSL to 0.10 at the highest. These rates increased slightly during the following decade but differences between GSL's remained about the same. These growth relationships resulted in much larger trees at the lower GSL's 15 years after the initial thinning.

Gross basal-area increment was positively correlated with stand density during each of the three growth periods. Annual growth ranged from 1.4 square feet per acre at the lowest GSL to 3.9 at one of the higher densities.

Growth in cubic volume was related to GSL. Large amounts of wood were produced on the higher GSL's, but this was accompanied by mortality from mountain pine beetle; growth was distributed on many trees that may never reach merchantable size. Timber stands in the midrange levels (GSL 80, 100 square feet) grew reasonable amounts of wood without serious beetle attack.

Preface

Growth of ponderosa pine, one of the most widely distributed pines in North America, is under study by the western Forest and Range Experiment Stations of the Forest Service, U.S. Department of Agriculture. This study is in response to increasing demands for better and more precise estimates of yields possible in intensively managed stands.

The Lookout Mountain thinning study in central Oregon is part of a westwide growing-stock levels study in even-aged ponderosa pine (Myers 1967). From a common study plan, each installation evaluates growth response to thinning in stand sizes growing on site qualities common to each region. Each installation is scheduled to run at least 20 years, with measurements at 5-year intervals and thinning at 10-year intervals, if appropriate.

Two of the six installations in this study are in the Black Hills of South Dakota, two are in Oregon, one is in northern Arizona, and one is in a plantation on the west slope of the Sierra Nevada in California.

This paper presents 15-year results from one installation in a naturally regenerated stand in central Oregon on the Pringle Falls Experimental Forest, Deschutes National Forest.

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1 **The Lookout Mountain Study**

2 **Methods**

4 **Results**

4 Growth Related to Stocking Level

6 Total Yield and Tree Size

8 **Mortality**

8 **Conclusions**

9 **Literature Cited**

9 **Metric Equivalents**

The Lookout Mountain Study

Previous publications on this study are:

Myers, Clifford A. Growing stock levels in even-aged ponderosa pine. Res. Pap. RM-33. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; **1967.** 8 p.

Schubert, Gilbert H. Growth response of even-aged ponderosa pines related to stand density levels. J. For. 69(12): 857-860; **1971.**

Schubert, Gilbert H. Silviculture of southwestern ponderosa pine: the status of our knowledge. Res. Pap. RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; **1974.** 71 p.

Schubert, Gilbert H. Silvicultural practices for intensified forest management. In: Trees—the renewable resource: Proceedings, Rocky Mountain Forest Industry conference; 1976 March; Tucson, AZ, **1976:** 37-54.

Severson, Keith E.; Boldt, Charles E. Options for Black Hills forest owners: timber, forage, or both. Rangeman's J. 4(1): 13-15; **1977.**

Oliver, William W. Growth of planted ponderosa pine thinned to different stocking levels in northern California. Res. Pap. PSW-147. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; **1979.** 11 p.

Six growing-stock levels of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) are being tested in the Lookout Mountain study, on the Deschutes National Forest, 25 miles southwest of Bend, Deschutes County, Oregon. The study area lies at an elevation of about 5,000 feet (lat. 43° 46′ N.; long. 121° 43′ W.) on the east slope of the Cascade Range. Plots are on the south-facing slope of Lookout Mountain in the Pringle Falls Experimental Forest.

Average annual precipitation is estimated to be 40 inches, only about 10 percent of which falls during the May through September growing season. A snowpack of 3 feet is common. Daytime temperatures during the growing season range between 70° and 90° F. Nights are cool, and frost may be expected any time of the year.

The soil is a deep, well-drained, cindery over medial (loamy) Typic Cryorthent, formed in dacite pumice originating from the eruption of Mount Mazama (Crater Lake) 6,600 years ago. The pumice averages 3 feet deep and is underlain by buried sandy loam material developed in older volcanic ash containing some cinders and basalt fragments.

The *Pinus ponderosa/Ceanothus velutinus* plant community (Franklin and Dyrness 1973) (in an *Abies concolor/Ceanothus velutinus* climax association) covers extensive areas on the mountainside. In the study area, snowbrush ceanothus (*Ceanothus velutinus* Dougl. ex Hook.) predominates, with an occasional golden chinkapin (*Castanopsis chrysophylla* (Dougl.) DC.). Western prince's-pine (*Chimaphila umbellata* (L.) Bart.) is abundant.

A few, very old ponderosa pine were scattered throughout the area and probably furnished seed for establishment of the stand under study. The average site index estimated from these dominant and codominant old-growth trees is 92 feet at 100 years (Meyer 1961).

Before thinning, the timber stand was dense and tree crowns were narrow, with only about 25 percent of total tree height in crown. Pretreatment average stand characteristics compared to normal (Meyer 1961) were:

	Pretreatment stand average	Normal site index 92, age 65
Trees per acre	1,133.0	462.0
Stand d.b.h. (inches)	6.3	9.3
Basal area (ft^3/acre)	240	216
Height (feet)	48	—
Volume (ft^3/acre)	4,704	5,335

Average height of trees left after thinning was only loosely related to growing-stock level; it varied from 55 to 67 feet and averaged 61.5 feet, which would relate to a site index of only about 80. Apparently, excess density had a suppressing effect on height growth. The 100 largest trees per acre averaged about 11 inches d.b.h. and 65 feet tall.

Methods

The six growing-stock levels (GSL's) being tested at Lookout Mountain are 30, 60, 80, 100, 120, and 150 (fig. 1). These GSL's are the basal area in square feet per acre that the stand has—or will have—after thinning, when the stand diameter averages 10 inches or more. The actual basal area after thinning stands less than 10 inches can be determined from figure 1. Each growing-stock level was replicated three times. Treatments were assigned at random to 18 one-half-acre plots with 33-foot buffer areas. Plots were scattered throughout a quarter section where site and stand density differences could be minimized. A pretreatment stand inventory was made by measuring d.b.h. of each tree. Reserve trees were marked, and the plots precommercially thinned in the fall of 1965 when the stand was 65 years old. The stand was rethinned to the various assigned GSL's later.

Thinning slash was lopped and scattered. Special precautions were taken to keep large pieces of slash several feet from leave trees because the slash was heavily invaded after thinning by pine engraver beetles (*Ips pini* Say). Fortunately, only two leave trees were lost when beetles emerged from the slash. All trees were tagged the following spring and d.b.h. measured to the nearest 0.1 inch. Fifteen trees on each thinned plot were selected for measuring with an optical dendrometer. Selection of these trees was made by constructing a diameter-distribution series for each plot and then selecting trees at random from each diameter class so that the complete range of diameter classes was represented. Stem volume inside bark in cubic feet and board feet were calculated by Grosenbaugh's (1964) STX computer program. All trees measured with an optical dendrometer from one GSL treatment were combined (45 trees), and an equation of the form Log vol. = a + b log d.b.h. was computed. A separate equation for each measurement period was calculated. These equations were used to determine volume of individual trees on each plot.

An estimate of average total tree height at each measurement period was calculated by using tree heights from the 45 measured trees per treatment in an equation of the form Total height = a + b log d.b.h. Each plot, except plot 9, was rethinned to its assigned GSL 10 years after the initial thinning. Many trees in and around plot 9 were attacked by bark beetles; thus we decided to forego any thinning at this time. Actually, few trees were killed by the attack, but several may have been weakened.

Analysis of variance was used to test for differences in treatment and the interaction between treatment and growth period. Where significance at the 5-percent level of probability was found, separate GSL and period differences were tested by Tukey's test. The original long-term intent of the west-wide study was to use response-surface techniques to look at the relationships of growth GSL on various sites after all data from the six studies have been collected for 20 years.

Stand characteristics are presented in table 1 and figure 2.

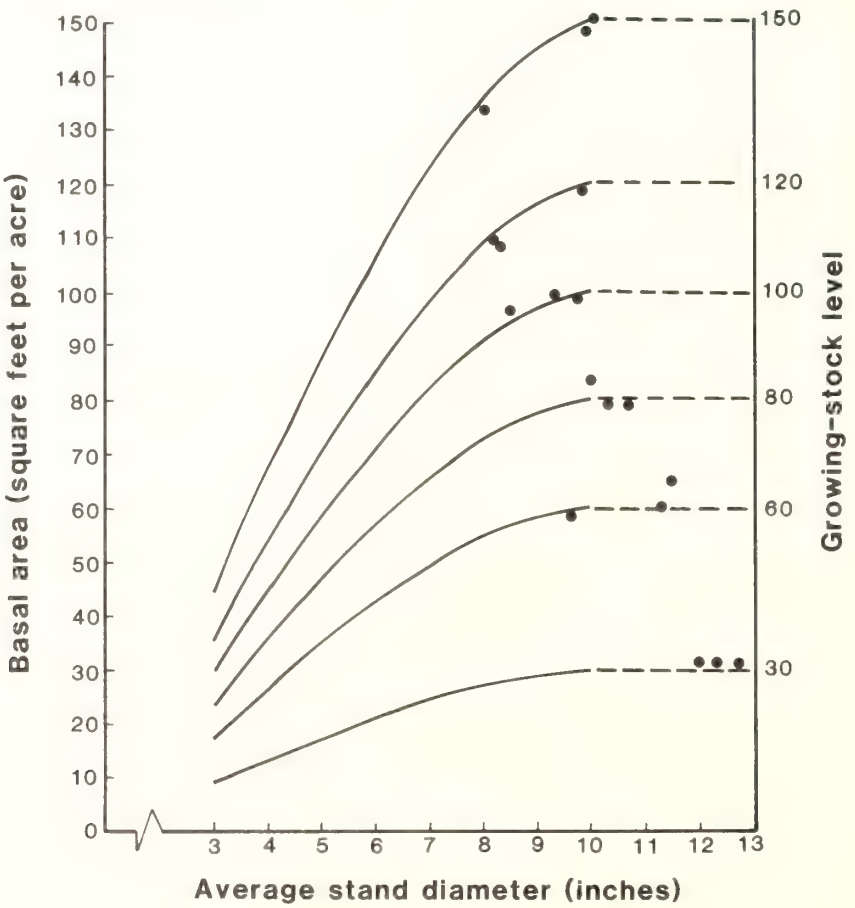

Figure 1.—Relation of basal area to average stand diameter. Black dots represent basal area and average diameters of plots after initial thinning on this study. Solid curves represent guiding curves, set forth by Myers (1967), for stands with average diameters less than 10 inches after thinning. Dashed lines show that basal area or GSL is to be held constant by repeated decadal thinning after the stand averages 10 inches or more.

Table 1—Average stand characteristics per acre for each growing-stock level in an even-aged ponderosa pine stand on an above-average site in central Oregon

Growing-stock level	Total	D.b.h. 1/	Height	Basal area	Volume	
					Total 2/	Merchantable 3/
Square feet/acre	Number of trees	Inches	Feet	Square feet/acre	Cubic feet	Board feet
			TREES CUT IN INITIAL THINNING			
30	925	6.4	50	209.5	4,482	--
60	1,032	5.7	42	181.8	3,546	--
80	915	5.7	42	160.9	2,731	--
100	1,015	5.3	39	154.5	2,356	--
120	1,193	4.3	35	119.2	1,883	--
150	650	4.9	37	86.0	1,554	--
			TREES REMAINING AFTER THE FIRST THINNING AT AGE 65			
30	38	12.3	67	31.49	775	2,726
60	97	10.8	65	61.20	1,441	4,180
80	140	10.3	63	81.10	1,792	4,787
100	215	9.2	59	98.53	2,071	3,992
120	272	8.7	55	112.81	2,357	4,452
150	308	9.3	60	144.03	3,235	7,122
			TREES CUT IN SECOND THINNING AT AGE 75			
30	16	14.4	73	18.22	496	2,023
60	35	11.0	62	23.30	576	1,824
80	51	10.4	64	30.02	735	2,096
100	64	8.5	56	25.46	528	565
120 4/	79	8.1	54	28.21	610	600
150	73	8.0	58	25.70	583	671
			TREES REMAINING AFTER SECOND THINNING AT AGE 75			
30	22	15.8	76	29.89	827	3,539
60	58	13.8	72	60.04	1,624	6,473
80	88	13.0	71	80.68	2,126	8,025
100	146	11.2	67	99.64	2,341	7,491
120 5/	207	10.5	63	123.77	3,000	8,616
150	223	11.1	70	148.99	3,975	12,894

1/Quadratic mean diameter breast high.

2/Volume inside bark from ground to tip.

3/Scribner board feet to a 5-inch tip inside bark and an 8-foot minimum log length; that is, most logs are 9 inches d.b.h. outside bark and larger.

4/Average of two plots. One plot not thinned at age 75.

5/Average of three plots.

Figure 2.—Ten years after thinning the Lookout Mountain study to growing-stock levels of 30 (A), 100 (B), and 150 (C).

Results

Growth Related to Stocking Level

Diameter—Growing-stock level had some influence on periodic annual diameter growth. Trees in the lowest GSL grew the most rapidly at the annual rate of 0.28 inch in the first period, 0.30 in the second, and 0.32 in the third period—compared to only about 0.11 inch at the highest GSL in all three periods (table 2). Generally, growth rate gradually decreased from GSL 30 to GSL 100, and then not much difference occurred between the three highest GSL's (fig. 3). Specifically, no significant differences in diameter growth rate occurred between the three highest GSL'S (100, 120, 150) during the last period (fig. 3, table 2). Each successive GSL from 100 through 30 grew significantly better during the 5 years after the second thinning.

A trend of increasing diameter growth with time was found, but this was significant only in the 30, 60, 80, and 100 GSL's. No significant difference in growth from the second to the third period occurred in any of the GSL's, although a thinning took place just at the start of the third growth period.

Before thinning, snowbrush ceanothus was sparsely distributed. After the initial thinning, this understory vegetation was completely covered by thinning slash. A very sparse distribution of these plants is beginning to appear 15 years after the first thinning, but their effect on diameter growth is considered negligible in comparison to the significant influence observed in thinned sapling stands within a few miles of this study area (Barrett 1973).

Basal Area—Periodic, gross annual basal-area increment was significantly and positively correlated with stand density during each of the three growth periods (fig. 4, table 2). Trees in plots thinned to GSL 30 in the first period grew 1.4 square feet per acre compared to a minimum growth rate of 3.9 square feet at one of the higher densities in the second period. Significance of gross growth-rate differences is complex (table 2).

Table 2—Mean periodic annual growth 5 and 10 years after initial thinning and during the 5 years after the second thinning

Growing-stock level 1/	D.b.h. 2/	Basal area		Volume			
		Gross	Net	Gross	Net	Gross	Net
Square feet/acre	Inches	Square feet/acre		Cubic feet/acre 3/		Board feet/acre 4/	
		0 TO 5 YEARS AFTER INITIAL THINNING					
30	5/ 0.28 a	1.4 a	1.4 a	45 a	45 a	228 a	228 a
60	0.18 b	2.0 ab	1.6 a	68 a	59 ab	353 ab	336 ab
80	0.16 b	2.6 b	2.6 a	93 c	93 ab	455 bc	455 b
100	0.10 cd	2.3 b	2.1 a	55 ab	51 a	307 ad	307 ab
120	0.12 ce	2.7 b	2.2 a	91 c	81 ab	384 bd	381 ab
150	0.10 de	3.5 c	3.2 a	117 d	112 b	540 c	537 b
		5 TO 10 YEARS AFTER INITIAL THINNING					
30	5/ 0.30 a	1.9 a	1.9 a	65 c	65 a	338 a	338 a
60	0.22 b	2.8 b	2.8 ab	93 a	93 ab	487 b	487 acd
80	0.19 bc	3.3 bd	3.3 ab	121 b	120 b	611 b	611 bd
100	0.14 cd	3.2 bef	3.2 ab	109 ab	109 bc	506 b	506 acd
120	0.14 ce	3.9 cde	3.8 b	130 b	129 bd	578 b	578 b
150	0.11 de	3.7 cdf	2.9 ab	170 d	153 cd	795 c	751 b
		0 TO 5 YEARS AFTER SECOND THINNING					
30	5/ 0.32 a	1.3 a	1.3 a	39 a	39 a	208 e	208 a
60	0.25 b	2.2 bc	1.9 a	73 b	63 a	383 a	340 ab
80	0.21 b	2.7 bd	2.6 a	82 b	80 a	423 abd	420 bc
100	0.16 d	2.9 cd	2.9 a	84 bc	84 a	408 ac	408 ab
120	0.14 d	3.1 d	2.8 a	95 bc	85 a	502 abc	471 bd
150	0.12 d	3.2 d	1.6 a	107 c	65 a	533 dc	397 acd

1/Stand density expressed as the basal area per acre that will remain after thinning when average stand diameter is 10 inches or more.

2/Based only on trees living through the period.

3/Volume inside bark from ground to tip.

4/Scribner board feet to a 5-inch top inside bark and an 8-foot minimum log length, that is, most 9 inches d.b.h. outside bark and larger.

5/Means within growth periods not showing the same letter differ significantly ($P \leq 0.05$ by Tukey tests).

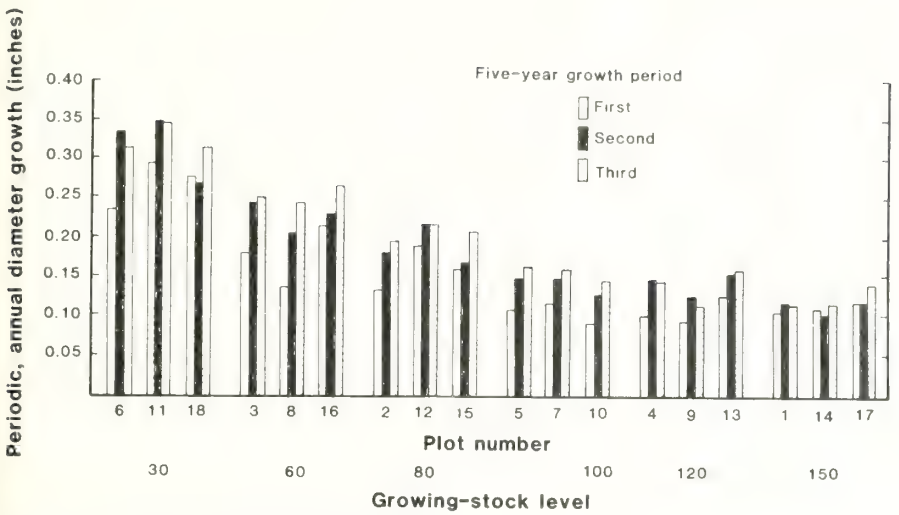

Figure 3.—Periodic, annual growth in diameter of ponderosa pine poles thinned to six different growing-stock levels on a productive site in central Oregon.

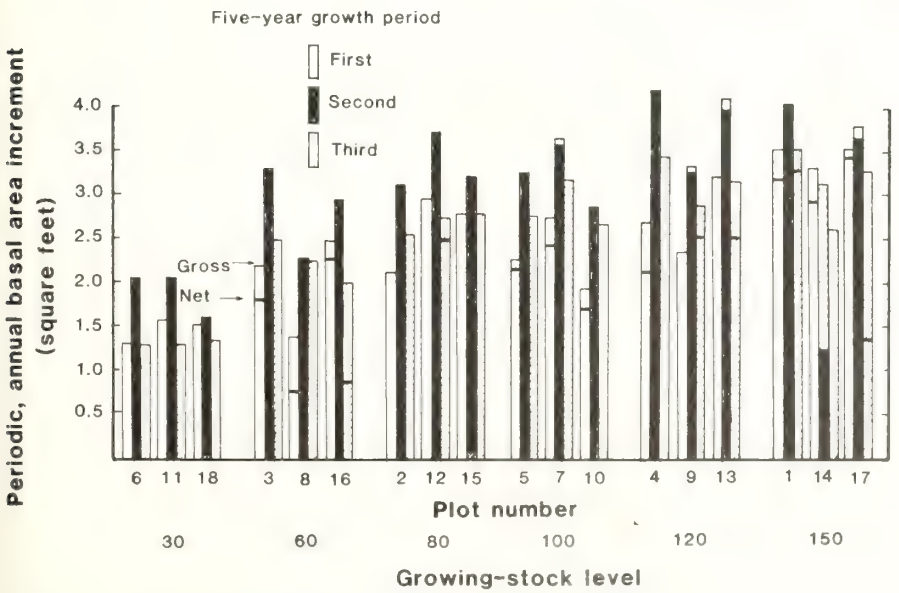

Figure 4.—Periodic, annual basal-area increment of ponderosa pine poles thinned to six different growing-stock levels on a productive site in central Oregon.

Significant differences in net basal-area increment were observed only in the second growth period, but net differences are not very useful or meaningful because of the erratic nature of mortality. Only 5 of the 18 plots had losses in basal area that exceeded 10 percent of gross growth. Two of the five occurred in GSL 150 plots. No losses in basal area occurred in the GSL 30 plots.

Height—Attempts to detect differences in height growth between growing-stock levels was difficult because of the limited sample of heights (15 per plot) and the within-treatment variation encountered. Analysis of variance with the data available indicated no significant differences in height growth between GSL's.

Volume—Periodic growth in total stem volume was strongly related to growing-stock level throughout all periods (fig. 5). Net growth was adversely affected by mortality on some plots, especially during the last period. GSL 100 was a poor producer during the first period in all replications, for some reason. Increment consistently rose from the first 5-year period to the second in all plots and then dropped consistently in the third period after the second thinning. Growth dropped even on plot 9, which was not thinned. During the second period, when growth peaked in all GSL's, annual plot increment ranged from 65 ft^3/acre at GSL 30 to 170 ft^3/acre at GSL 150.

During the first two periods, differences in volume growth were large and significant among the lowest and highest GSL's, similar to what Oliver (1979) reported in the GSL study in California. Some differences in intermediate GSL's were observed, probably because of the peculiar lower production of intermediate GSL 100. During the third period, differences were large and significant among the lowest and highest GSL's, but were smaller and nonsignificant among the intermediate GSL's and their adjacent treatment level (table 2). If we look at periodic growth during the first decade as a function of initial basal area or GSL (fig. 6), we find a steady rise in volume production up to the highest GSL, similar to Oliver's (1979) observation during the first 5 years. During the 5-year period after the second thinning (fig. 6), there is a

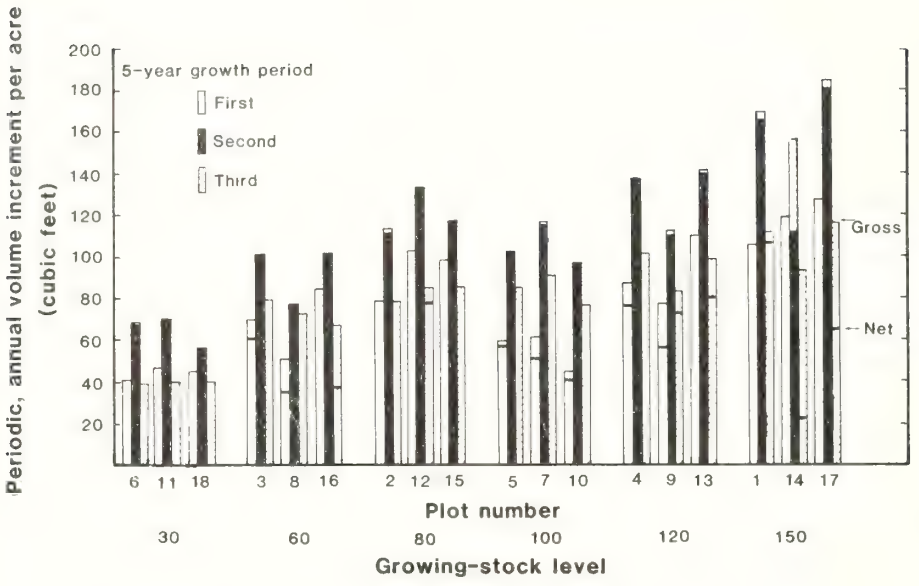

Figure 5.—Periodic, annual net- and gross-volume increment of ponderosa pine poles thinned to six different growing-stock levels on a productive site in central Oregon.

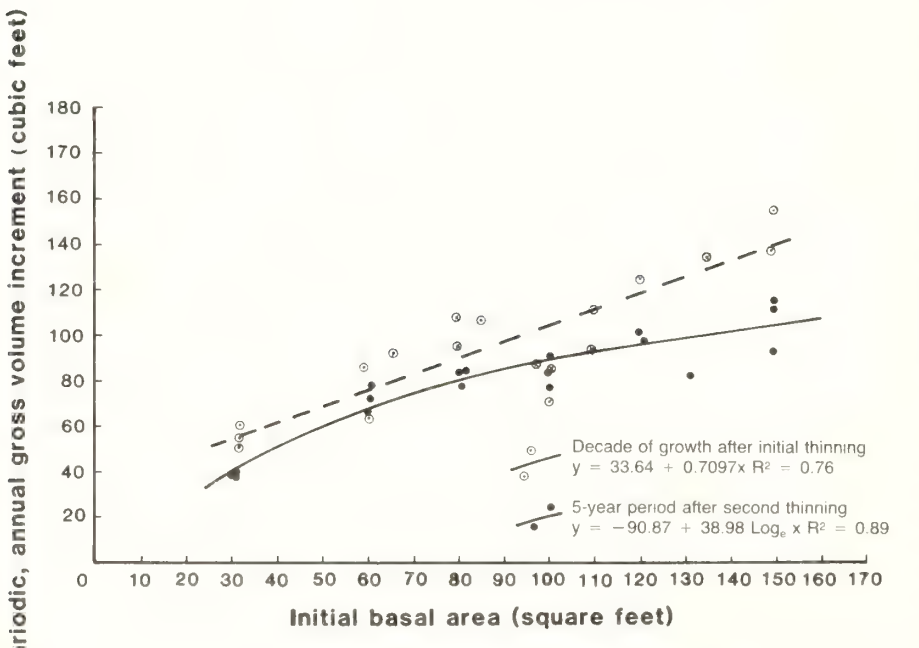

Figure 6.—Periodic, annual gross-volume increment during the decade after initial thinning and during the 5 years after the second thinning.

suggestion of leveling off in volume production at the higher levels. This may simply reflect having to cut relatively more trees at the higher GSL's to accommodate the required thinning to the desired growing-stock level after 10 years of growth.

Board-foot volume and volume growth are presented (tables 1, 2), but have limited meaning relative to GSL because many trees at the higher GSL's are growing into board-foot sizes. The smallest tree considered merchantable was 9 inches d.b.h., capable of producing an 8-foot log with a 5-inch top inside bark at the small end, a realistic utilization on many operations in eastern Oregon.

Total Yield and Tree Size

Although drawing conclusions about long-term yield would be premature, the outlook is favorable. Total yield, including the second thinning only, 15 years after initial thinning, increased with higher growing-stock levels (fig. 7). The highest GSL yielded about 5,000 cubic feet of wood and the lowest GSL 1,500 cubic feet. Although the highest GSL yielded substantially higher amounts of wood than other GSL's, it contained many (94 per acre) trees below 9 inches d.b.h. (fig. 8) when the second thinning from below was made. For example, in the second thinning at GSL 150, 73 trees were thinned from below that averaged 8.0 inches d.b.h., yielding only 671 board feet of merchantable wood. In comparison, GSL 80 had only 9 trees below 9 inches d.b.h. To cut the stand back to GSL 80, 51 trees were cut, with an average d.b.h. of 10.4 inches and 2,096 board feet.

Although trees at GSL 30 grew much faster in diameter, developed vigorous crowns, and suffered no mortality from beetle attack, considerable yield was sacrificed (fig. 7) by thinning to this low level. Considerable growth loss has also occurred at GSL 60.

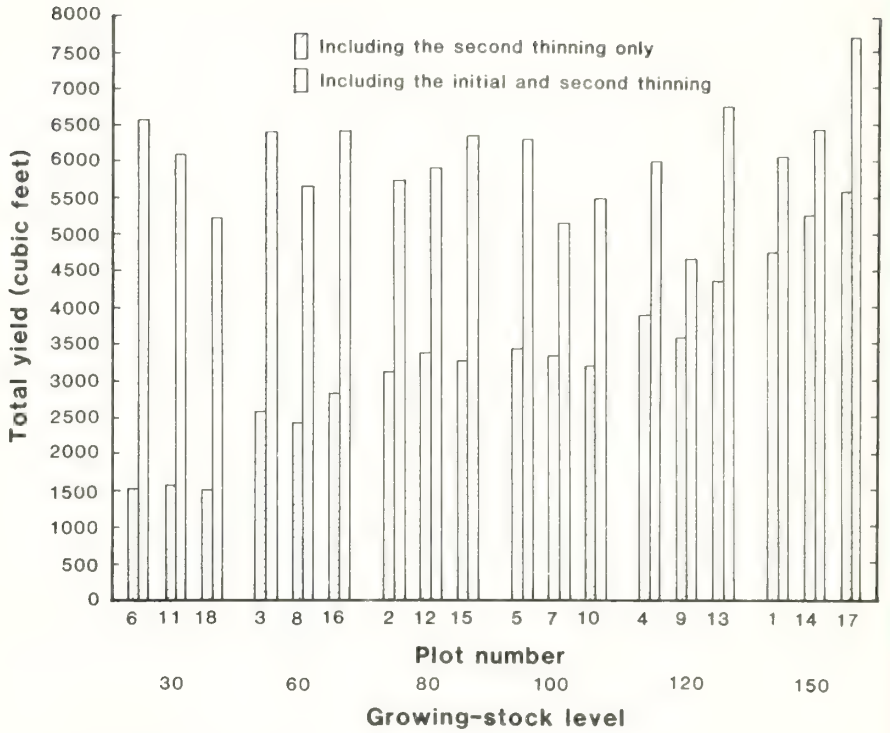

Figure 7.—Gross total yield 15 years after the initial thinning.

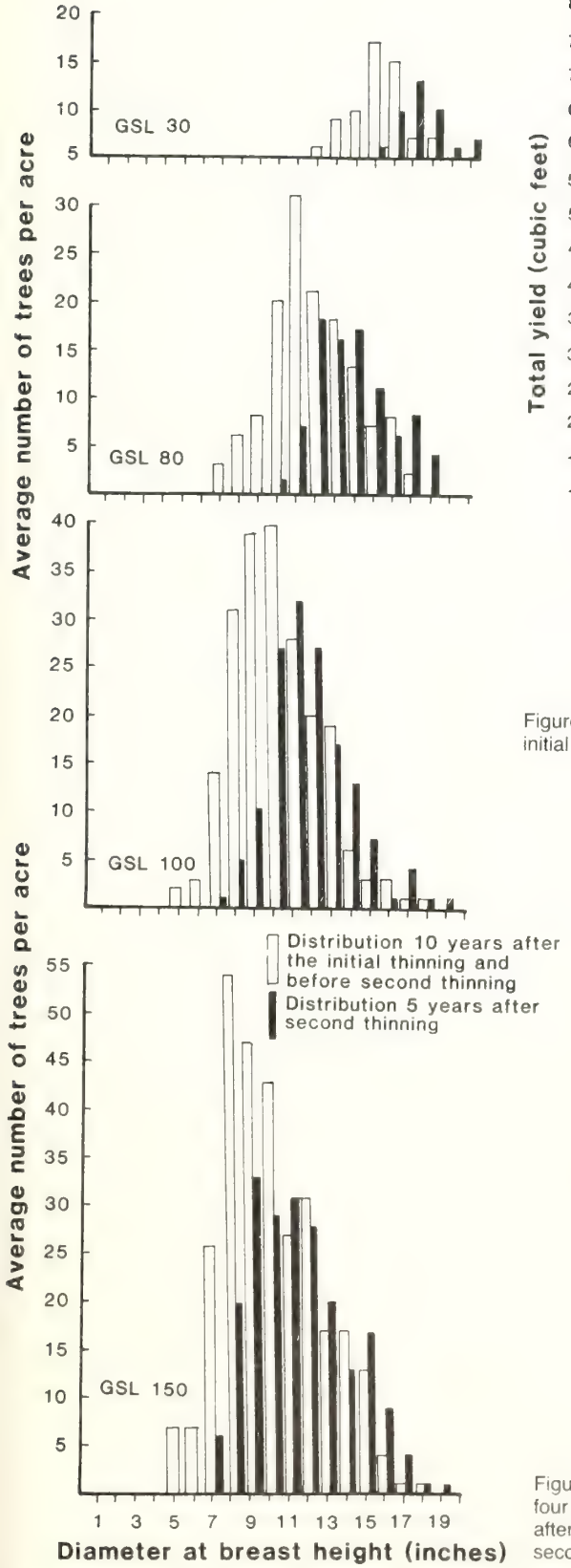
Average number of trees per acre
GSL 30
GSL 80
GSL 100
GSL 150
Distribution 10 years after the initial thinning and before second thinning
Distribution 5 years after second thinning
1 3 5 7 9 11 13 15 17 19
Diameter at breast height (inches)

Figure 8.—Average diameter distribution on four of the six growing-stock levels 10 years after the initial thinning, and 5 years after the second thinning

Mortality

All of the tree deaths could be associated with mountain pine beetle (*Dendroctonus ponderosae* Hopk.) attacks. Damage from the insect in this study was found to be closely related to tree vigor (Larsson et al. in press). No agents such as dwarf mistletoe, needle blight, or root rot could be found contributing to low vigor on the trees attacked by beetles.

Visible, cumulative beetle mortality before thinning from age 0 to 65, as observed in pretreatment inventory, averaged 26 trees per acre, with consistent mortality on all plots. After initial thinning, this pattern began to change, and the distribution of mortality was altered—by far the highest number of trees being attacked by beetles were in the greater growing-stock levels, (figs. 4, 5, and 7), although this was erratic from plot to plot. Attacks occurring at the low GSL's were on trees of low vigor only.

Larsson et al. 1983 concluded, however, that the population of beetles was relatively low during the last two periods of observation, because only 6 percent of all trees attacked were killed.

Sartwell and Stevens (1975) concluded from studies in both Oregon and South Dakota that stand basal area of 148 square feet per acre should be a critical maximum, above which stands are likely to become severely infested. In our study, Larsson et al. 1983 also found this basal area provided most trees with sufficient vigor to withstand at least moderate attack. Maintaining stands at still lower stocking levels, as recommended for intensive management by Barrett (1979), should insure a greater margin of safety from attack by mountain pine beetle.

Conclusions

This stand is producing periodic volume increments at the higher GSL's far in excess of what might be anticipated from Meyer's (1961) yield table for site index 92. This is not an unusual observation for this area. A thinning study in a 100-year-old adjacent stand produced above-normal volume growth during a 30-year period (Barrett 1974). The stand under study here had a structure far different from normal, which retarded past volume growth. After thinning, mortality was probably reduced and net growth increased substantially even with reduced growing stock. (See page 7 for comparison with a normal stand.)

Although growth of this stand appears to be above normal, similar stands in this plant community may not perform as well. A site class can have more than one productive potential (Assman 1970), and that may be what is reflected here.

Precommercial thinning of pole stands, such as that described here, does not seem operationally feasible. Board-foot volume differences between the highest GSL and subsequent lower GSL's indicate that a light commercial thinning could be made instead. In the process of thinning and slash treatment, whether mechanical or prescribed fire, unwanted trees could be destroyed and the GSL left that is compatible with other resource-management objectives. Productive sites such as this should be precommercially thinned at an early age, so that the growth capacity of the site can be concentrated on trees that will eventually be used.

Another reason for thinning pole stands is safety against beetle attack. Beetle populations were low in this area; losses were minimal compared to other places, where beetle populations are high on sites with average-to-good indexes, and tree losses frequently unacceptable. Another advantage in commercially thinning these overdense pole-sized stands is that diameter growth is increased, and trees reach merchantable size classes faster, thus helping to fill the existing size-class gap between advanced sapling-sized reproduction and old-growth that exists in many pine stands in eastern Oregon.

Selecting the most appropriate GSL is a compromise between GSL's producing high amounts of wood fiber and GSL's that will produce target diameters in a desired time frame. In the 15-year period of observation in this study, some latitude is apparent in the choice of an appropriate GSL between 60 and 100 square feet, without sustaining an undesirable loss in periodic increment or eventual yield.

Managers may want to compare results from this study with existing stocking-level curves for ponderosa pine (Barrett 1979), where site index is IV or better (Meyer 1961). Comparisons show roughly that GSL's 60, 80, and 100 stay within reasonable distance of the recommended and maximum curves during the 15 years of observation. GSL 30 is below the minimum stocking curve, and GSL's 120 and 150 are far above the maximum curve in an area that approaches the critical maximum above which stands are likely to become severely infested with mountain pine beetle (Sartwell and Stevens 1975).

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Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 acre = 0.405 hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.069 97 cubic meter/hectare
1 tree/acre = 2.471 trees/hectare

Barrett, James W. Growth of ponderosa pine poles thinned to different stocking levels in central Oregon. Res. Pap. PNW-311. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 9 p.

This paper presents 15-year results of one installation of a west-wide study of growing-stock levels in even-aged ponderosa pine. Growth was related to growing-stock level in a 65-year-old pole stand on an above average site. Periodic growth is presented for 10 years after the initial thinning and for 5 years after a second thinning to six assigned growing-stock levels.

Annual growth in diameter during the 5 years after initial thinning ranged from an average of about 0.28 inch at the lowest growing-stock level to 0.10 at the highest. These rates increased slightly during the following decade, but differences between growing-stock levels remained about the same. These growth relations resulted in much larger trees at the lower growing-stock levels 15 years after the initial thinning.

Keywords: Growing stock (-increment/yield, thinning effects, even-aged stands, improvement cutting, stand density, ponderosa pine, *Pinus ponderosa*.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Seasonal Changes in Chemical Composition and Nutritive Value of Native Forages in a Spruce-Hemlock Forest, Southeastern Alaska

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Abstract

HANLEY, THOMAS A.; McKENDRICK, JAY D. Seasonal changes in chemical composition and nutritive value of native forages in a spruce-hemlock forest, southeastern Alaska. Res. Pap. PNW-312. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 41 p.

Twenty-two forages from Admiralty Island, southeastern Alaska, were monitored bimonthly for one year to assess seasonal changes in their chemical composition: neutral detergent fiber, acid detergent fiber, cellulose, lignin/cutin, in-vitro dry-matter digestibility, total nitrogen, phosphorus, potassium, calcium, magnesium, sodium, copper, manganese, iron, and zinc. Seasonal fluctuations were pronounced but generally paralleled the pulse of plant growth in spring-summer. Only minor differences were found in chemical composition of forages from two study areas and results of this study did not differ greatly from results of other studies in southeastern Alaska and the Pacific Northwest. Forbs, half-shrubs, and shrub leaves were consistently the most nutritious forages, especially during winter. Seasonally low levels of digestible energy, nitrogen, and phosphorus were identified as the most important potential limitations of these forages in meeting the nutritional needs of herbivores.

Keywords: Forage production, nutrient analysis, native plants, phytochemistry, phenology, seasonal variations, Alaska (southeastern), southeastern Alaska, wildlife habitat.

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Introduction

The forests of southeastern Alaska provide habitat for a variety of wildlife. As logging and forest management intensify, it becomes increasingly important to understand the relationships between animals and their habitat. Although nutritional relationships provide the biological basis for such an understanding (Moen 1973), little is known about plant-herbivore relationships in southeastern Alaska forests. Livestock grazing has been unimportant in the local economy, so few forage evaluations have been done. The few investigations of forage quality have centered on principal forages utilized by deer (*Odocoileus hemionus sitkensis*) (Klein 1965, Rose 1982, Schoen and Wallmo 1979). Klein (1965) determined the concentrations of nitrogen, fat, fiber, ash, nitrogen free extract, calcium, and phosphorus in 14 species from May through August in central southeastern Alaska. Schoen and Wallmo (1979) measured the nitrogen and fiber content of 10 species during January in northern southeastern Alaska. Rose (1982) measured the nitrogen, phosphorus, total nonstructural carbohydrates, and fiber content of 10 species during January, April, June, and September in southern southeastern Alaska. Data have not been adequate, however, to evaluate seasonal fluctuations in chemical composition and nutritive value across a broad range of forages or to evaluate the role of these fluctuations in limiting the energy, protein, and mineral nutrients available to southeastern Alaska herbivores over an annual cycle.

The objectives of this study were: (1) to obtain a baseline description of the chemical composition of major plant species in southeastern Alaska forests; (2) to quantify seasonal (phenological) changes in chemical composition; (3) to examine site-to-site variability in chemical composition; and (4) to examine the nutritive value of the native forages relative to the dietary requirements of herbivores. The study was intended to provide a basis for modeling nutritional relationships of habitat for herbivores.

Methods

Study Area

Forage species were collected at two sites on Admiralty Island at approximately 58° N latitude, 134° W longitude: Hawk Inlet on the Mansfield Peninsula and Winning Cove on the Glass Peninsula. The sites were 53 km apart (straight line distance). Both were low-elevation forests of uneven-aged, old-growth Sitka spruce (*Picea sitchensis*) [1] and western hemlock (*Tsuga heterophylla*). Dominant understory species included huckleberry (*Vaccinium ovalifolium* and *V. alaskensis*), fool's huckleberry (*Menziesia ferruginea*), devilsclub (*Oplopanax horridum*), and skunk-cabbage (*Lysichiton americanum*), with lesser amounts of bunchberry dogwood (*Cornus canadensis*), trailing bramble (*Rubus pedatus*), foamflower (*Tiarella trifoliata*), and associated plants. Elevation ranged from 0 to 70 m. Climate was cool and wet, typical of the southeastern Alaska coastal rainforest.

Field Collection and Laboratory Analysis of Forage Samples

Samples from 29 species of plants were collected during 1981. Twenty-two species were monitored bimonthly throughout the year at the Hawk Inlet site (table 1), and 17 species were sampled during January and March at the Winning Cove site (table 2). An additional 7 miscellaneous species from other habitats and study sites were sampled for comparative purposes. Samples of vascular species consisted of current annual growth only. Leaves were collected and analyzed separately from stems for tall shrubs (huckleberry, fool's huckleberry, devilsclub, and salmonberry, (*Rubus spectabilis*)). Samples were clipped in the field, refrigerated overnight, oven-dried at 40 °C, ground in a mill with 20-mesh screen, and stored in sealed plastic bags at room temperature (20 °C) until final drying at 50 °C immediately preceding laboratory analyses.

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[1] Nomenclature for vascular plant names follows Hulten (1968) and Hitchcock and Cronquist (1973).

Table 1—Forages collected and dates of collection at the Hawk Inlet study site in 1981

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
Forbs and ferns:						
Coptis aspleniifolia	X	X	[1] X	X	X	X
Dryopteris dilatata	X	X	X	X	X	X
Listera cordata			[1] X	[1] X		
Lysichiton americanum		X	X	X	X	
Maianthemum dilatatum			X	X		
Moneses uniflora	X	X	X	X	X	X
Streptopus spp.			[1] X	X		
Tiarella trifoliata	X	X	X	X	X	X
Half-shrubs:						
Cornus canadensis	X	X	X	X	X	X
Rubus pedatus	X	X	X	X	X	X
Vaccinium spp.[2]	X	X	X	X	X	X
Shrubs:						
Menziesia ferruginea—						
Leaves			X	X	X	
Stems	X	X	[3] X	X	X	X
Oplopanax horridum—						
Leaves			X	X	X	
Stems			X	X	X	X
Rubus spectabilis—						
Leaves			X	X	X	
Stems			[1] X	X	X	
Vaccinium alaskensis—						
Leaves			X	X	X	
Stems	X	X	[1] X	X	X	X
Conifers:						
Picea sitchensis	X	X	X	X	X	X
Tsuga heterophylla	X	X	X	X	X	X
Graminoids:						
Deschampsia caespitosa	X		X	X	X	X
Carex lyngbyaei			X	X	X	X

See footnotes at end of table

Table 1—Forages collected and dates of collection at the Hawk Inlet study site in 1981 (continued)

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
Lichens:						
Usnea spp.	X	X	X	X	X	X
Moss:						
Rhytidiadelphus loreus	X	X	X	X	X	X
Algae:						
Fucus furcatus	X	X	X	X	X	X

[1] Insufficient material for total ash determination.
[2] Decumbent, evergreen variety.
[3] Insufficient material for detergent analysis, in-vitro dry-matter digestibility, or total ash determination.

Table 2—Forages used in t-test comparisons of Hawk Inlet and Winning Cove study sites

Forage class and species	January 9-15	March 12-20
Forbs and ferns:		
Coptis aspleniifolia	X	X
Dryopteris dilatata		X
Lysichiton americanum		X
Moneses uniflora	X	X
Tiarella trifoliata	X	X
Half-shrubs:		
Cornus canadensis	X	X
Rubus pedatus	X	X
Vaccinium spp.[1]	X	X
Shrubs (stems):		
Alnus rubra		X
Menziesia ferruginea	X	X
Vaccinium alaskensis	X	X
Conifers:		
Picea sitchensis	X	X
Tsuga heterophylla	X	X
Graminoids:		
Elymus arenarius	X	
Lichens:[2]		
Lobaria spp.	X	
Usnea spp.	X	X
Moss:		
Rhytidiadelphus loreus[2]	X	X

[1] Decumbent, evergreen variety.
[2] Lichens and moss were not included in comparisons involving detergent analysis.

Laboratory analyses consisted of sequential detergent analysis (Goering and Van Soest 1970) as modified by Mould and Robbins (1982) for fiber constituents and Tilley and Terry in-vitro digestion trials (Goering and Van Soest 1970) of 12- and 48-h duration using cattle rumen fluid. Nutrient contents were determined in the following manner: Aliquots of pulverized and dried tissue were weighed into glass digestion tubes and digested for 1 h in a 40-unit aluminum block at 400 °C. The digestion mixture consisted of 7 ml H_2SO_4-H_2SeO_3 and 3 ml 30-percent H_2O_2 per aliquot. The acid component was prepared by dissolving 97 g H_2SeO_3 in 100 ml deionized water. That solution was then mixed with 2 350 ml concentrated H_2SO_4. After digestion, samples were cooled and each was brought to 75-ml volume with deionized water. An aliquot from each digest was sealed in polyethylene sample vials. Nitrogen (N) and phosphorus (P) were measured simultaneously on a Technicon Auto Analyzer II [2]. Potassium (K), magnesium (Mg), sodium (Na), iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) were measured on a Perkin-Elmer 5000. All analyses were compared with National Bureau of Standards' orchard leaf reference sample. Analytical accuracy was monitored by including one known composition tissue in each lot of 40 samples analyzed. All analyses were expressed on a dry-weight (at 50 °C) basis.

Data Analysis

Data for the samples from the Hawk Inlet study site are reported in the appendix to provide a baseline description of the chemical composition of major plant species. Annual means were calculated for all species. To analyze seasonal changes in chemical composition, we calculated means for each forage class (forbs and ferns, half-shrubs, shrubs, graminoids, etc.) for each collection date. In calculating means for shrubs, we weighted leaf and stem values in proportion to the leaf:stem ratio of 150 ovendry huckleberry twigs clipped at the collection site at the time of each collection.

As an index of the amount of digestion-inhibiting secondary plant compounds, we calculated the difference between the amount of dry matter that disappeared in 48-h in-vitro tests and the digestibility predicted by the equation of Mould and Robbins (1982), which is based on the fiber composition of forage. The Mould-Robbins equation is based on forages that were relatively free of digestion-inhibiting secondary compounds. We believe that values of in-vitro dry-matter disappearance that were exceptionally lower than predicted by the Mould-Robbins equation indicate a high content of digestion inhibitors.

Variability in chemical composition of forages from site to site was examined across species by comparing means of samples collected from the Hawk Inlet and Winning Cove study sites in January and March. Any biases stemming from differential phenology at the two study sites were minimized, because plants were relatively dormant at those times. Means for both collection dates and each chemical variable of samples from the two sites were compared and tested for statistical significance with a paired-sample t-test, pairing by species (table 2), with $P \leq 0.05$ considered as statistically significant.

Nutritive value of the forages was evaluated by comparing chemical composition and digestibility with standards of the National Research Council (1976) for nutritional requirements of beef cattle. These requirements are well known and are used here only as an index of the nutritional value of southeastern Alaska forages for herbivores and to identify major potential nutritional limitations.

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[2] Use of brand names does not imply endorsement by either the U.S Department of Agriculture or the University of Alaska.

Results and Discussion

Fiber Constituents

Neutral detergent fiber (NDF), which consists mainly of the total cell wall fraction of the forage, was greatest in moss, graminoids, and shrub stems, and least in lichens, algae, forbs, and shrub leaves (table 3). Neutral detergent solubles (NDS), mainly the cell cytoplasm and its constituents, were especially great in skunk-cabbage, heartleaf twayblade (*Listera cordata*), and deerberry (*Maianthemum dilatatum*). Lignin-cutin content, a component of NDF, was relatively great in moss, conifers, shrub stems, and spreading woodfern (*Dryopteris dilatata*). While NDS tends to be rapidly and completely digested by ruminants, lignin-cutin is virtually nondigestible and retards cellulose digestion (Goering and Van Soest 1970).

Forbs, ferns, and half-shrubs had the greatest NDS content throughout the year (fig. 1). Conifers and shrubs, on the other hand, were consistently high in lignin/cutin (fig. 2). The fiber content and composition of conifers, forbs, and half-shrubs remained relatively stable throughout the year, whereas in shrubs, it exhibited pronounced seasonal fluctuations corresponding with the production and loss of leaves.

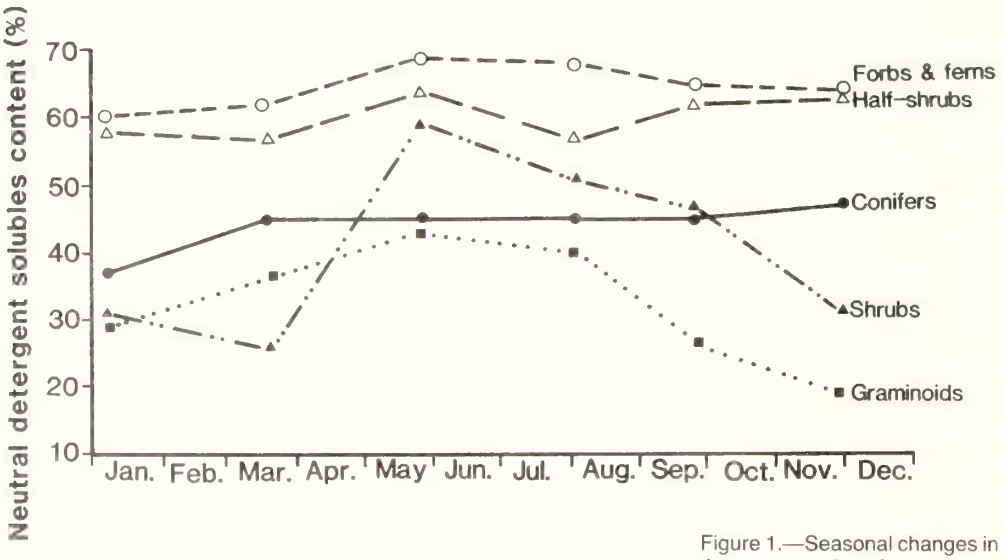

Figure 1.—Seasonal changes in the concentration of neutral detergent solubles.

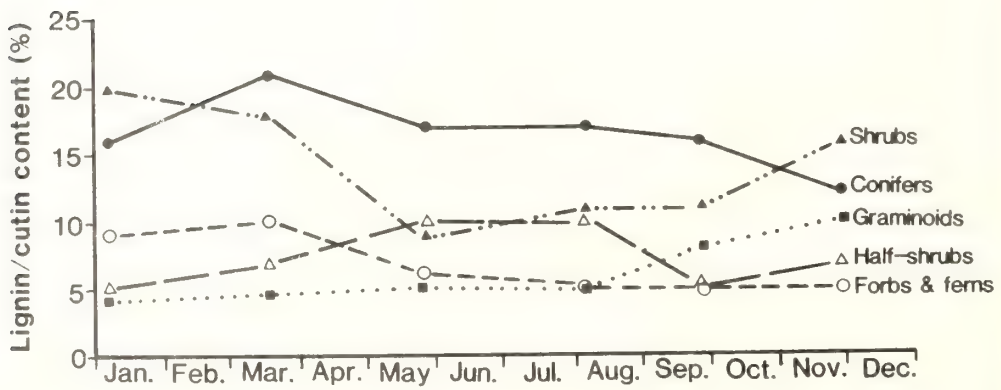

Figure 2.—Seasonal changes in the concentration of lignin/cutin.

Table 3—Mean values of variables measured in detergent analysis for each species

Forage class and species	NDF	ADF	Cellulose	Lignin/cutin
	Percent dry weight			
Forbs and ferns:				
Coptis aspleniifolia	43.8	28.7	24.1	4.2
Dryopteris dilatata	49.7	36.2	20.4	15.4
Listera cordata	23.9	16.6	13.4	3.2
Lysichiton americanum	20.8	13.6	10.4	2.0
Maianthemum dilatatum	25.3	16.4	14.1	1.5
Moneses uniflora	28.6	17.4	13.2	4.4
Streptopus spp.	27.3	19.3	17.1	0.9
Tiarella trifoliata	34.4	25.3	15.2	9.7
Half-shrubs:				
Cornus canadensis	32.3	21.5	14.8	6.1
Rubus pedatus	34.2	17.4	14.1	2.8
Vaccinium spp.[1]	53.3	35.4	22.4	12.8
Shrubs:				
Menziesia ferruginea—				
Leaves	38.2	23.0	15.0	7.8
Stems	74.8	56.1	31.6	18.2
Oplopanax horridum—				
Leaves	31.0	16.7	11.8	4.5
Stems	56.8	41.6	29.5	11.5
Rubus spectabilis—				
Leaves	30.4	14.0	9.0	5.1
Stems	66.2	42.3	29.8	12.4
Vaccinium alaskensis—				
Leaves	53.3	30.6	15.4	15.2
Stems	66.6	49.2	29.1	18.1
Conifers:				
Picea sitchensis	59.5	44.4	26.7	17.4
Tsuga heterophylla	52.4	38.7	22.4	15.1
Graminoids:				
Deschampsia caespitosa	69.1	36.4	27.5	6.2
Carex lyngbyaei	67.6	34.8	27.1	7.2
Lichens:				
Usnea spp.	27.5	4.5	[2] 1.6	[2] 2.2
Moss:				
Rhytidiadelphus loreus	81.8	51.6	30.8	20.1
Algae:				
Fucus furcatus	27.8	19.5	6.8	11.9

[1] Decumbent, evergreen variety.

[2] Lichens differ chemically from vascular plants; values reported are not really cellulose or lignin/cutin.

Dry Matter Digestibility

Differences in fiber composition among species were largely reflected in differences in in-vitro dry-matter digestibility (IVDMD) (table 4). Species high in NDS and low in lignin/cutin content tended to be digested most completely and rapidly (for example, skunk-cabbage, heartleaf twayblade, deerberry, and devilsclub leaves). The 48-h IVDMD values of several species, however, were much lower than would be expected on the basis of their fiber composition: twistedstalk (*Streptopus* spp.), trailing bramble, fool's huckleberry, salmonberry, Sitka spruce, western hemlock, hairgrass (*Deschampsia cespitosa*), sedge (*Carex lyngbyaei*), beard lichen (*Usnea* spp.), feathermoss (*Rhytidiadelphus loreus*), and rockweed alga (*Fucus furcatus*). Because both the detergent analysis and the Mould-Robbins equation were developed for vascular forages, particularly grasses and forbs, there are inherent problems in applying the technique and equation to lichens, moss, and algae. Conifers are known to contain high levels of digestion-inhibiting volatile oils (Oh and others 1967). The graminoids in this study contained an appreciable amount of silica during winter (mean ± standard deviation: 2.7 ± 3.2 percent for 8 random samples of graminoids taken in September through January, compared with 0.1 ± 0.1 percent for 4 random samples of graminoids taken in May through August, and 0.0 ± 0.0 percent for 15 random samples of dicots collected the year around).[3] Silica is known to inhibit the digestibility of dry matter (Van Soest and Jones 1968). The fact that IVDMD of the other species was lower than expected, however, indicates a relatively high content of digestion-inhibiting substances in them as well.

Forbs were highly digestible throughout the year (fig. 3). Half-shrubs also were highly digestible but apparently were more digestible in winter than in summer. Conifers were poorly digestible the year around, while IVDMD of shrubs paralleled changes in the production and loss of leaf tissue. Graminoids were relatively highly digestible in spring and early summer but poorly digestible in late fall and winter. Forbs and half-shrubs were the forages most rapidly digestible (fig. 4) in both summer and winter. Shrubs and graminoids were more rapidly digestible than conifers in summer but less rapidly digestible than conifers in winter. Effects of digestion inhibitors were most apparent in conifers, shrubs, and graminoids during winter (fig. 5).

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[3]Hanley, Thomas A. and McKendrick, J. D. Unpublished data on file at Forestry Sciences Laboratory, Juneau.

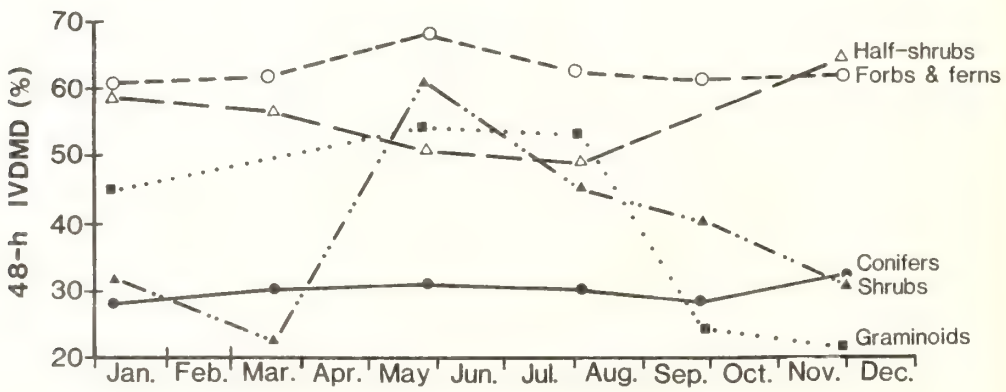

Figure 3.—Seasonal changes in 48-h in-vitro dry-matter digestibility (IVDMD).

Table 4—Mean values of in-vitro dry-matter digestibility trials for each species and percentage difference between observed (48-h) and predicted digestibility

Forage class and species	Digestibility 12 h	Digestibility 48 h	Difference between observed and expected [1]
	Percent dry weight		
Forbs and ferns:			
Coptis aspleniifolia	46.7	67.0	-2.6
Dryopteris dilatata	34.1	43.4	-9.1
Listera cordata	61.2	76.0	-5.3
Lysichiton americanum	63.5	78.0	-0.2
Maianthemum dilatatum	63.7	71.5	-12.4
Moneses uniflora	54.0	68.3	-6.0
Streptopus spp.	55.9	70.0	-21.1
Tiarella trifoliata	43.2	54.5	-8.8
Half-shrubs:			
Cornus canadensis	47.1	65.9	-5.2
Rubus pedatus	40.5	50.9	-30.0
Vaccinium spp.[2]	38.7	50.5	+8.1
Shrubs:			
Menziesia ferruginea—			
Leaves	39.9	50.3	-15.4
Stems	18.4	24.0	-36.3
Oplopanax horridum—			
Leaves	60.0	73.3	+10.0
Stems	43.3	53.7	+4.4
Rubus spectabilis—			
Leaves	45.2	46.1	-29.5
Stems	25.4	33.7	-21.5
Vaccinium alaskensis—			
Leaves	40.7	46.7	+15.2
Stems	27.6	34.1	-6.6
Conifers:			
Picea sitchensis	27.7	28.9	-28.0
Tsuga heterophylla	29.6	30.5	-34.3

See footnotes at end of table

Table 4—Mean values of in-vitro dry-matter digestibility trials for each species and percentage difference between observed (48-h) and predicted digestibility (continued)

Forage class and species	Digestibility 12 h	Digestibility 48 h	Difference between observed and expected [1]
	Percent dry weight		
Graminoids:			
Deschampsia caespitosa	29.7	37.9	-33.6
Carex lyngbyaei	31.0	39.4	-24.1
Lichens:			
Usnea spp.	18.8	21.5	-65.5
Moss:			
Rhytidiadelphus loreus	15.5	16.0	-29.5
Algae:			
Fucus furcatus	45.5	36.3	-39.7

[1] Percentage difference is [(Observed – Expected)/(Expected)] x 100, where Expected is the value predicted using the summative equation of Mould and Robbins (1982) for in-vitro apparent dry-matter digestibility of forages in which soluble phenolics and other digestion-inhibiting compounds are minimal. The equation of Mould and Robbins (1982) was for white-tailed deer (*Odocoileus virginianus*).
[2] Decumbent, evergreen variety.

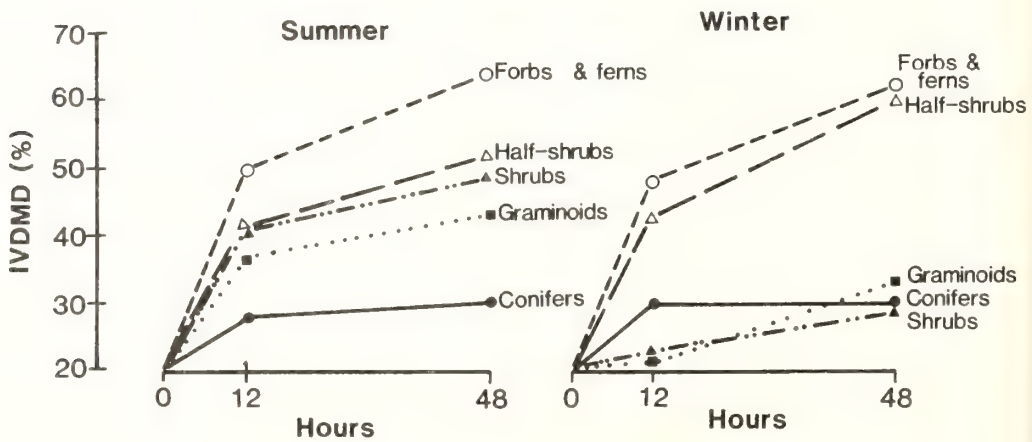

Figure 4.—Summer and winter values of 12- and 48-h in-vitro dry-matter digestibility (IDVMD) trials.

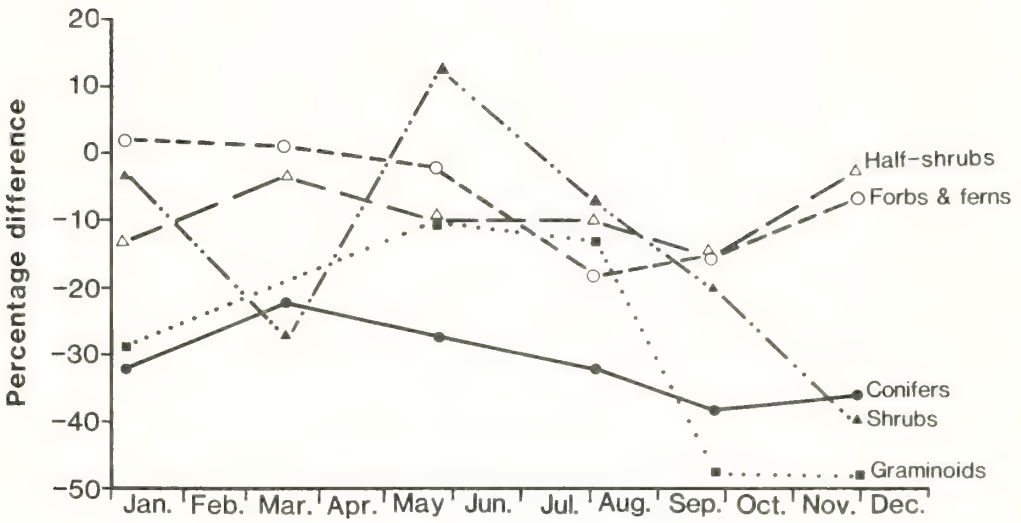

Figure 5.—Seasonal changes in percentage difference between observed and predicted digestibility (see table 4).

Macronutrients

Total ash concentration of the forages did not vary much seasonally, except in graminoids, which were collected along the beach-forest fringe and were exposed to periodic inundation by salt water (fig. 6). Forbs and half-shrubs were consistently highest in total ash concentration, while conifers and shrub stems were consistently low.

N concentration was greatest in forbs, ferns, half-shrubs, and shrub leaves (especially skunk-cabbage, twisted-stalk, and devilsclub leaves), and lowest in beard lichen and feathermoss (table 5). N concentration was consistently low in conifers but increased with summer growth in the other vascular species (fig. 7). P concentration exhibited a pattern nearly identical to that of N (table 5, fig. 8).

Forbs and ferns consistently contained the greatest amounts of K (table 5, fig. 9). Devilsclub leaves and stems and rockweed alga also were high in K. Lowest levels consistently occurred in beard lichen, feathermoss, and conifers. Graminoids and shrub stems were very low in K during winter and highest during the pulse of growth in spring and early summer.

Ca concentrations were generally about 3 to 4 times greater than P concentrations (table 5). In contrast to P, however, Ca was lowest during the pulse of growth in spring and early summer (fig. 10). Ca to P ratios were nearly balanced in shrubs and forbs in early summer but very unbalanced throughout the rest of the year. Ca concentration was consistently greatest in bunchberry dogwood and foamflower and consistently low in conifers, graminoids, beard lichen, feathermoss, and fool's huckleberry stems.

Throughout the year, herbaceous forage contained the greatest concentration of Mg (fig. 11). Beard lichen, feathermoss, conifers, and shrub stems contained the lowest levels. Na concentration was consistently low in conifers and half-shrubs, and was consistently greatest in rockweed alga, graminoids, and forbs (especially skunk-cabbage) (table 5, fig. 12). Shrubs were relatively high in Na during late summer and fall. Wide fluctuations in the Na concentration of graminoids probably reflected periodic inundation by salt water.

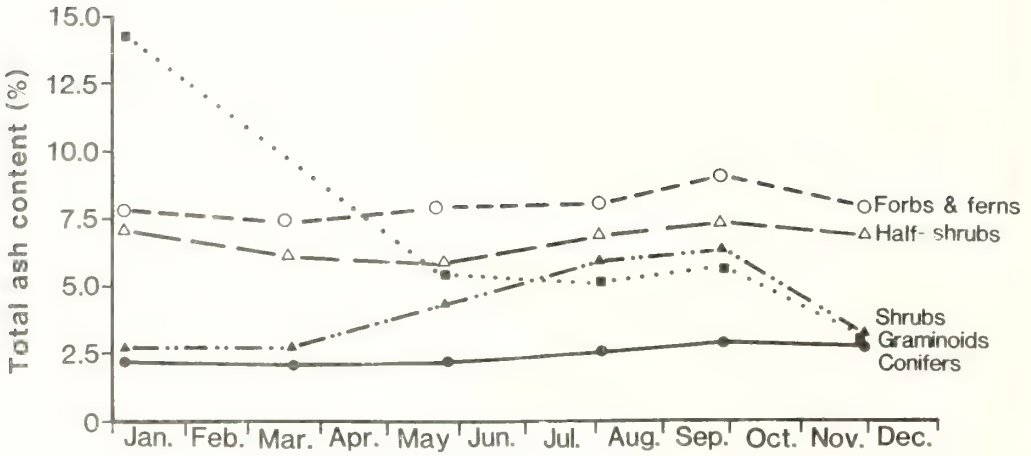

Figure 6.—Seasonal changes in the concentration of total ash.

Table 5—Mean values of percentage composition of macronutrients for each species

Forage class and species	N	P	K	Ca	Mg	Na
	Percent dry weight					
Forbs and ferns:						
Coptis aspleniifolia	1.81	0.22	1.65	0.79	0.31	0.06
Dryopteris dilatata	2.21	0.28	2.43	0.60	0.41	0.14
Listera cordata	2.51	0.42	3.99	0.63	0.21	0.27
Lysichiton americanum	5.63	0.52	2.49	1.33	0.23	1.01
Maianthemum dilatatum	2.03	0.30	2.40	0.50	0.22	0.66
Moneses uniflora	2.01	0.27	1.80	0.66	0.23	0.13
Streptopus spp.	3.48	0.38	4.32	1.15	0.33	0.06
Tiarella trifoliata	2.04	0.25	2.52	1.95	0.40	0.19
Half-shrubs:						
Cornus canadensis	2.01	0.22	1.04	2.58	0.49	0.05
Rubus pedatus	2.03	0.24	1.37	0.72	0.48	0.07
Vaccinium spp.[1]	1.52	0.16	0.75	0.85	0.20	0.09
Shrubs:						
Menziesia ferruginea—						
Leaves	2.48	0.24	1.19	0.62	0.40	0.47
Stems	1.18	0.15	0.85	0.35	0.17	0.09
Oplopanax horridum—						
Leaves	3.31	0.43	2.43	1.29	0.19	0.51
Stems	2.02	0.34	2.22	0.88	0.18	0.27
Rubus spectabilis—						
Leaves	2.25	0.35	1.30	0.89	0.40	0.21
Stems	0.96	0.20	1.30	0.46	0.17	0.17
Vaccinium alaskensis—						
Leaves	2.79	0.20	1.08	1.22	0.39	0.30
Stems	1.42	0.18	0.73	0.65	0.16	0.07

See footnote at end of table

Table 5—Mean values of percentage composition of macronutrients for each species (continued)

Forage class and species	N	P	K	Ca	Mg	Na
	Percent dry weight					
Conifers:						
Picea sitchensis	1.05	0.19	0.66	0.36	0.08	0.07
Tsuga heterophylla	1.01	0.19	0.51	0.34	0.10	0.08
Graminoids:						
Deschampsia caespitosa	1.43	0.14	1.06	0.21	0.17	0.68
Carex lyngbyaei	1.16	0.17	1.35	0.36	0.14	0.36
Lichens:						
Usnea spp.	0.44	0.10	0.22	0.29	0.06	0.07
Moss:						
Rhytidiadelphus loreus	0.62	0.13	0.43	0.30	0.09	0.07
Algae:						
Fucus furcatus	1.41	0.17	2.68	1.06	0.72	2.83

[1] Decumbent, evergreen variety.

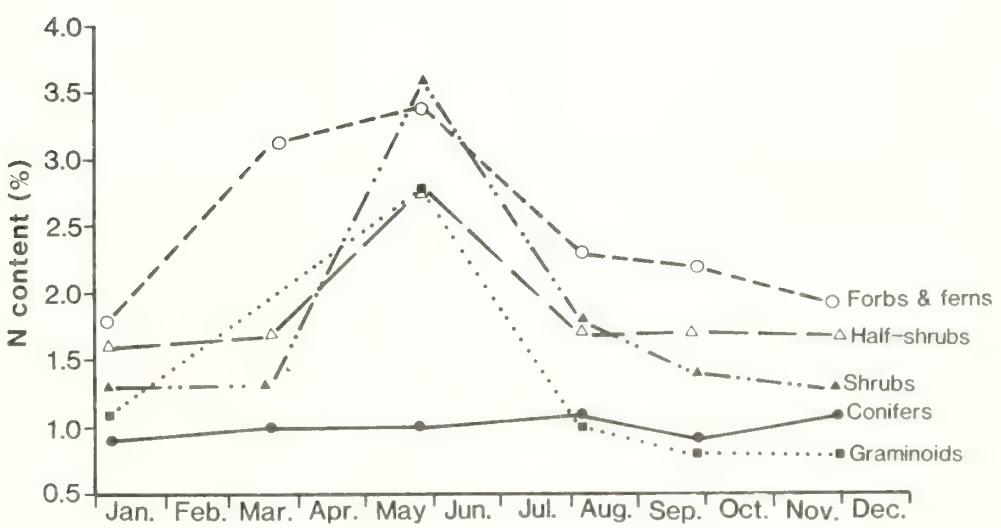

Figure 7.—Seasonal changes in the concentration of total nitrogen.

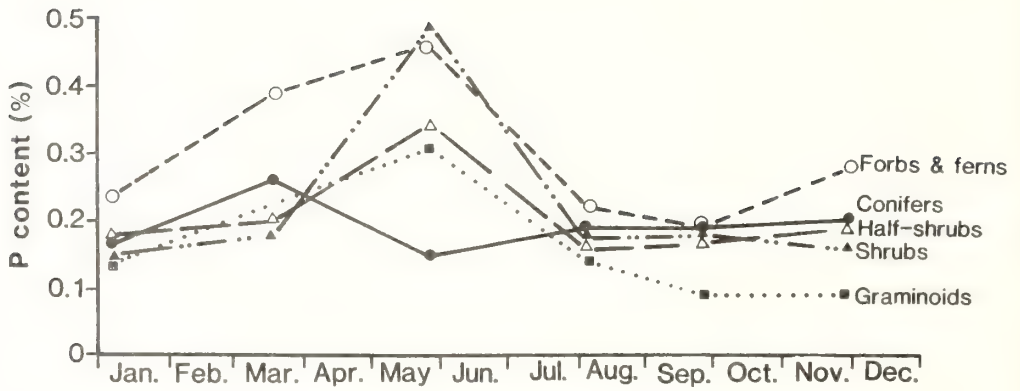

Figure 8.—Seasonal changes in the concentration of phosphorus.

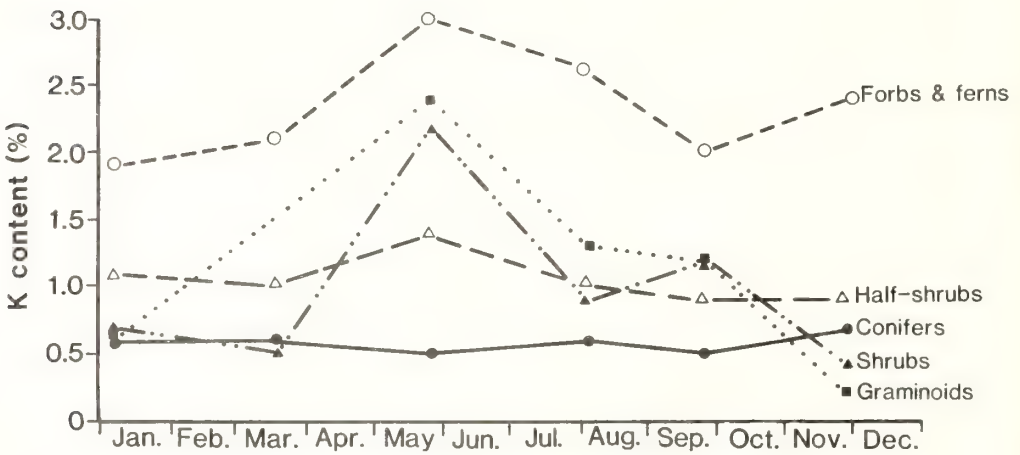

Figure 9.—Seasonal changes in the concentration of potassium.

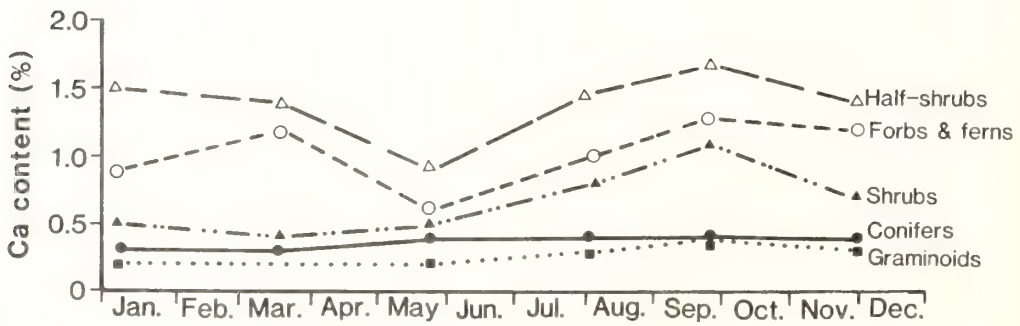

Figure 10.—Seasonal changes in the concentration of calcium.

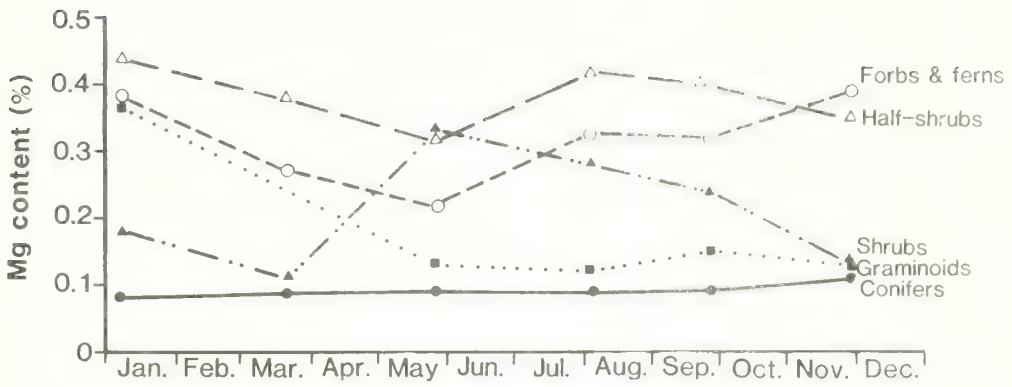

Figure 11.—Seasonal changes in the concentration of magnesium.

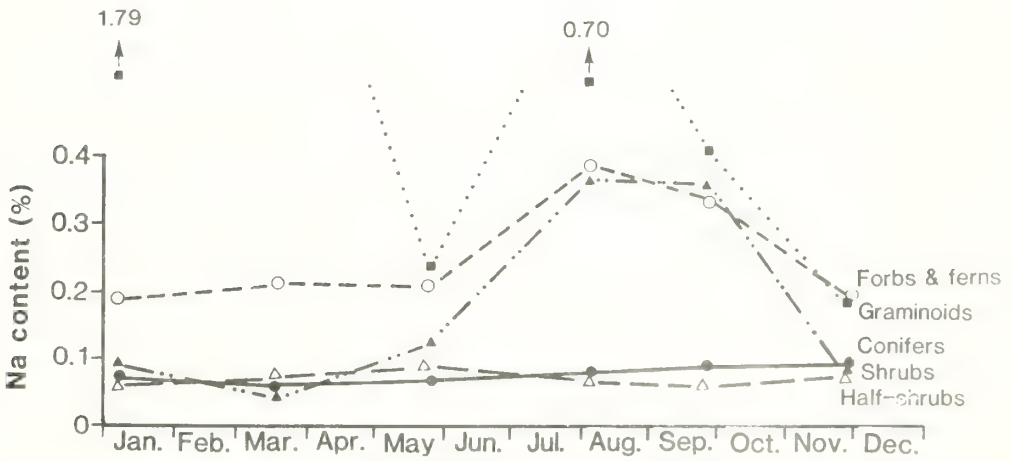

Figure 12.—Seasonal changes in the concentration of sodium.

Micronutrients

Shrubs and forbs (especially skunk-cabbage, heartleaf twayblade, and twisted-stalk) contained the greatest amounts of Cu throughout the year (table 6, fig. 13). Greatest concentrations occurred in spring and early summer. Concentrations in conifers, beard lichen, and rockweed alga were consistently low, and very low in graminoids in late fall and winter.

Very high concentrations of Mn were observed in many forages: skunk-cabbage, trailing bramble, huckleberry, fool's huckleberry, Sitka spruce, western hemlock, and feathermoss all averaged more than 1,000 ppm (table 6) and were consistently high (fig. 14). Graminoids, forbs, bunchberry dogwood, devilsclub, salmonberry, beard lichen, and rockweed alga contained moderate to low levels.

Table 6—Mean values of micronutrient composition for plant species

Forage class and species	Cu	Mn	Fe	Zn
	Parts per million dry weight			
Forbs and ferns:				
Coptis aspleniifolia	5.3	326.0	62.7	177.6
Dryopteris dilatata	9.2	668.1	105.7	44.2
Listera cordata	11.0	913.0	84.5	68.6
Lysichiton americanum	13.8	1794.8	101.8	43.4
Maianthemum dilatatum	3.0	523.9	39.5	23.6
Moneses uniflora	8.2	609.8	169.0	34.9
Streptopus spp.	10.0	296.1	68.0	52.4
Tiarella trifoliata	6.5	321.9	237.8	46.7
Half-shrubs:				
Cornus canadensis	5.2	211.6	75.3	86.6
Rubus pedatus	7.2	1237.6	98.8	31.9
Vaccinium spp.[1]	7.0	3117.3	57.5	33.4
Shrubs:				
Menziesia ferruginea—				
Leaves	10.0	16656.7	62.0	86.6
Stems	11.8	7139.2	22.8	40.5
Oplopanax horridum—				
Leaves	16.0	242.4	64.0	42.6
Stems	11.8	84.4	38.3	65.4
Rubus spectabilis—				
Leaves	5.0	84.8	58.7	82.0
Stems	18.3	36.9	19.3	116.4
Vaccinium alaskensis—				
Leaves	11.3	1961.3	51.3	18.6
Stems	12.0	2021.6	23.2	39.5
Conifers:				
Picea sitchensis	3.2	1299.3	23.3	27.8
Tsuga heterophylla	3.3	1947.2	66.2	14.2
Graminoids:				
Deschampsia caespitosa	4.0	201.1	254.2	20.6
Carex lyngbyaei	2.8	695.6	102.0	22.6
Lichens:				
Usnea spp.	1.7	220.9	56.7	28.6
Moss:				
Rhytidiadelphus loreus	5.2	1050.8	348.3	23.8
Algae:				
Fucus furcatus	1.8	43.5	158.2	22.2

[1] Decumbent, evergreen variety.

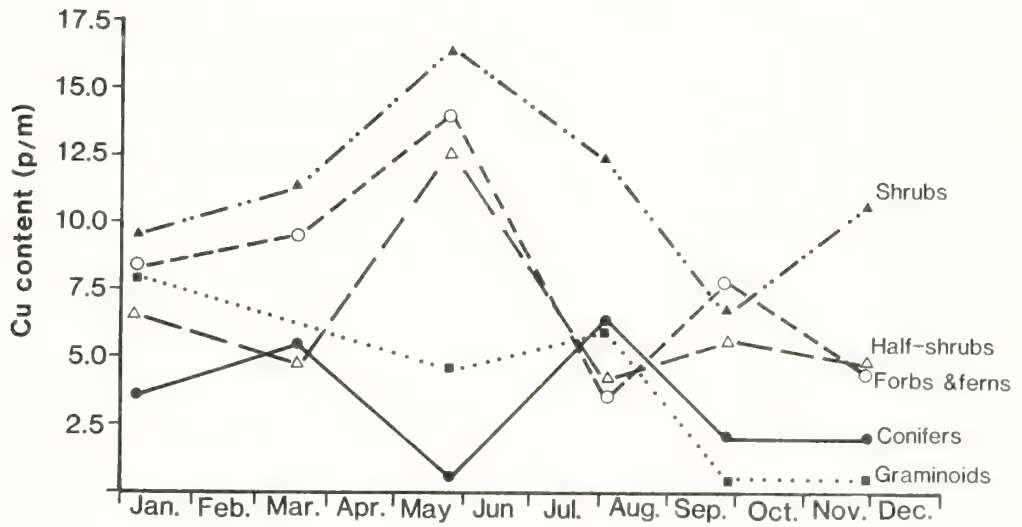

Figure 13.—Seasonal changes in the concentration of copper.

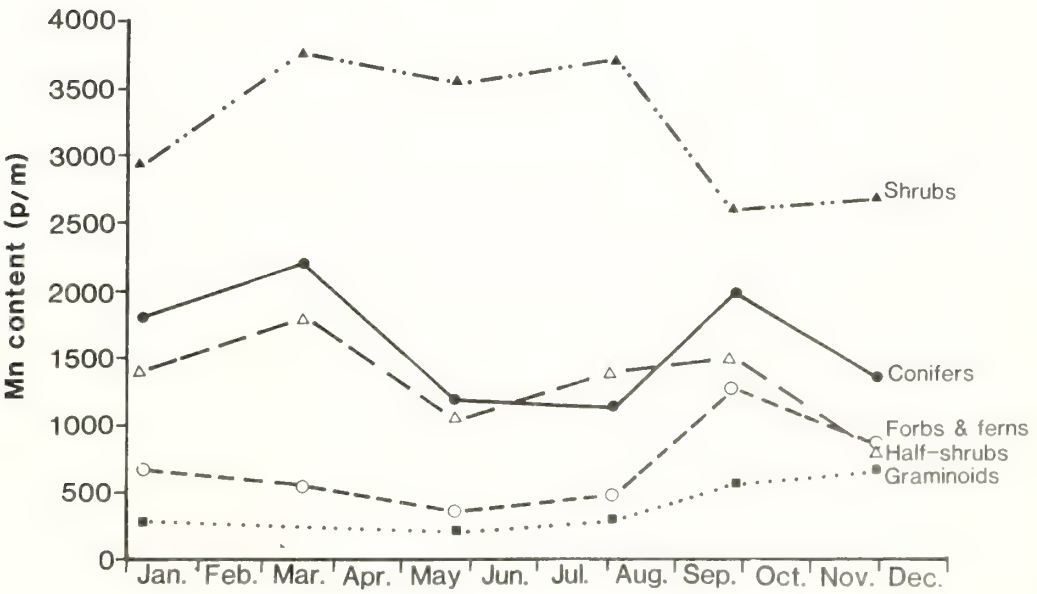

Figure 14.—Seasonal changes in the concentration of manganese.

Fe concentrations were greatest in forbs, ferns, feathermoss, and rockweed alga throughout the year (table 6, fig. 15). High concentrations in graminoids (especially hairgrass) corresponded with peak concentrations of total ash and Na and probably reflected recent inundation by salt water. Shrubs, conifers, and beard lichen were consistently low in Fe.

Zn values were greatest in fernleaf goldthread (*Coptis aspleniifolia*), bunchberry dogwood, and salmonberry (table 6). They were relatively stable throughout the year in half-shrubs, graminoids, and conifers (fig. 16).

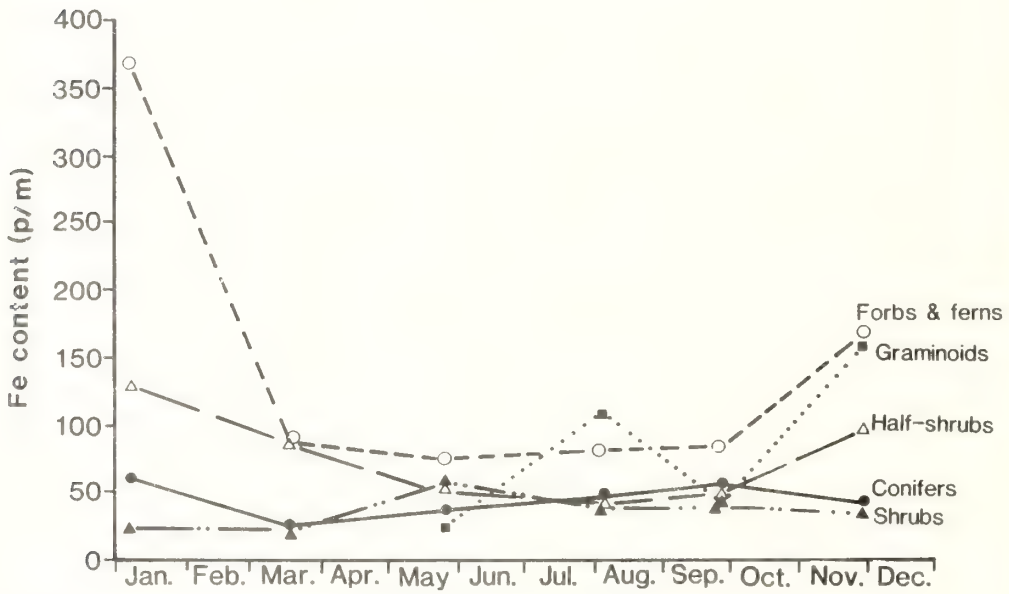

Figure 15.—Seasonal changes in the concentration of iron.

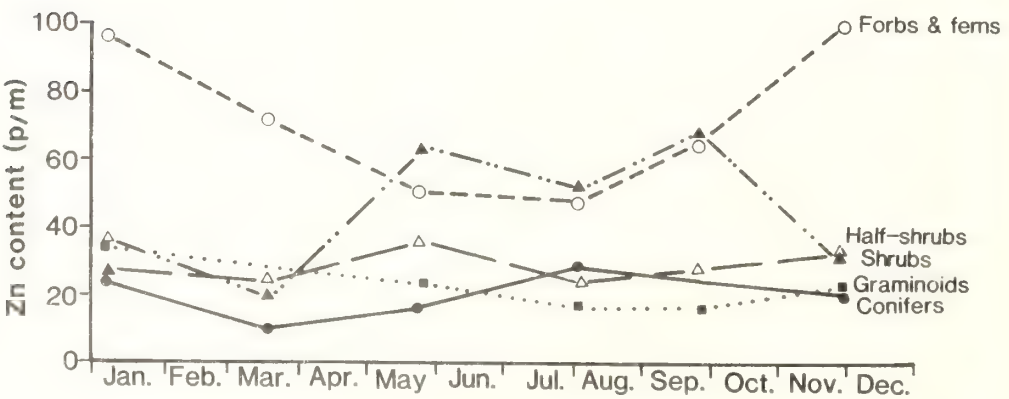

Figure 16.—Seasonal changes in the concentration of zinc.

Miscellaneous Species from Other Habitats

The seven miscellaneous forages we analyzed came from a variety of habitats. Each differed from samples of its respective forage class from Hawk Inlet in one or more nutritional variables (table 7). The subalpine forb, deer-cabbage (*Fauria crista-galli*) was especially high in IVDMD, Na, Cu, and Zn, and low in K and Ca. Crowberry (*Empetrum nigrum*), a half-shrub from muskeg, was high in lignin/cutin and Cu, and low in IVDMD, N, P, K, Ca, and Mg. Red alder (*Alnus rubra*) stems were low in NDF (high in NDS) and Mn. Labrador-tea (*Ledum palustre*), a shrub from muskeg, was low in NDF and Cu, and high in IVDMD and Fe. Alaska yellow cedar (*Chamaecyparis nootkatensis*) was high in IVDMD, total ash, Ca, and Zn, and low in NDF, P, and Mn. Lyme grass (*Elymus arenarius*) was very high in Fe, but it, like the other graminoids, was subject to periodic inundation by salt water. The foliose lichen *Lobaria* differed from beard lichen, being higher in NDF, "lignin/cutin," N, K, Mn, and Fe. All forages from miscellaneous sources except deer-cabbage had 48-h IVDMD values much lower than expected on the basis of the Mould-Robbins equation for fiber constituents. Deer-cabbage appeared relatively free of digestion-inhibiting secondary compounds.

Table 7—Chemical composition and dry-matter digestibility of 7 miscellaneous forages collected in various habitats in 1981

	Fauria Crista-galli, subalpine, 8/17	*Empetrum nigrum*, muskeg, 3/26	*Alnus rubra* stems, beach, 3/20	*Ledum palustre*, 1/ muskeg, 3/26	*Chamaecyparis nootkatensis* forest, 2/25	*Elymus arenarius* beach, 1/9	*Lobaria* spp forest, 1/9
	Percent						
NDF	28.3	53.4	51.8	49.9	39.7	77.3	61.0
ADF	12.4	39.6	39.4	49.9	31.1	39.6	29.3
Cellulose	10.6	17.4	18.2	19.2	22.6	23.7	15.8
Lignin-Cutin	1.7	22.2	21.1	15.6	8.6	5.1	9.8
12-h IVDMD	69.7	22.5	31.1	29.6	38.7	20.5	28.0
48-h IVDMD	78.6	29.9	34.2	39.9	47.3	31.0	29.2
Observed-Expected DMD	+3.1	-21.5	-15.4	-12.2	-22.8	-46.3	-31.5
Total Ash	8.5	2/	2.0	1.7	5.4	17.2	2.3
N	2.61	0.90	1.77	1.09	1.00	0.92	3.57
P	0.26	0.08	0.15	0.10	0.12	0.11	0.19
K	1.07	0.22	0.40	0.28	0.44	0.42	0.63
Ca	0.57	0.45	0.31	0.39	1.74	0.18	0.15
Mg	0.36	0.10	0.12	0.09	0.11	0.37	0.07
Na	1.48	0.03	0.09	0.04	0.04	0.81	0.10
	Parts per million						
Cu	15.0	9.0	9.0	6.0	3.0	5.0	4.0
Mn	740.0	314.2	69.2	747.6	73.9	370.2	1180.4
Fe	67.0	56.0	44.0	258.0	35.0	4000.0	160.0
Zn	225.1	21.8	30.5	60.7	163.4	34.6	34.1

1/ Includes both stems and leaves.
2/ Insufficient amount of sample for ash determination.

Comparisons Between Study Areas

Of 36 comparisons of means between the Hawk Inlet and Winning Cove study areas, only 3 were statistically different (table 8). In January, Hawk Inlet forages were lower in P and higher in Cu than the Winning Cove forages; there were no differences, however, in March. Similarly, although Hawk Inlet forages were lower in Mg concentration than Winning Cove forages in March, there was no such difference in January. Generally, there appeared to be no biologically significant differences in forages from the two study areas.

The Hawk Inlet forages differed slightly from those reported by other investigators in southeastern Alaska and the Pacific Northwest (table 9). No clear geographic pattern is evident, however, and the results were generally very similar. For example, the very high N values reported in this study for skunk-cabbage are similar to those reported by both Klein (1965) and Rose (1982). Klein also observed a Ca to P ratio greater than unity (about 2:1) on all four of his study areas. There was, however, a major discrepancy between our results for beard lichen and those reported by others. Mean annual 48-h IVDMD for beard lichen from Hawk Inlet was 21.5 percent. In contrast, Rochelle (1980) reported a mean annual value of 72.5 percent for *Alectoria sarmentosa,* a different beard lichen but similar to *Usnea* spp. in appearance, N concentration, and fiber composition. *Alectoria sarmentosa* collected in November at Hawk Inlet had a 48-h IVDMD of 26.3 percent, in comparison to 23.9 percent for *Usnea* spp. collected at the same time and place. The difference between Rochelle's results and ours probably reflects the difference in source of rumen inoculum. Rochelle used deer rumen fluid; we used cattle rumen fluid. The difference for most species is minor; for example, Rochelle's results and ours differed little for huckleberry and western hemlock (table 9). The chemical structure of lichens differs from that of vascular forages, however, and our cattle rumen fluid probably contained few microbes adapted for lichen digestion. Rochelle's IVDMD values for lichens are probably more appropriate than ours for deer on diets containing lichens.

Nutritive Value

The nutrient requirements of beef cattle (table 10) provide one standard for evaluating the nutritive value of the Hawk Inlet forages. Assuming a gross energy content of 4.4 kcal g^{-1} and a direct, linear relationship between digestible dry matter and digestible energy (Rittenhouse and others 1971, Mautz and others 1974), it is apparent that digestible dry matter must be at least 43 to 52 percent to meet maintenance requirements during winter and 43 to 70 percent to meet maintenance, growth, and lactation requirements during summer. Of the Hawk Inlet forages, forbs and half-shrubs satisfy the winter requirement, while forbs, half-shrubs, shrub leaves, and graminoids satisfy the summer requirement. The digestible energy content of conifers and shrub stems is inadequate throughout the year for maintenance requirements. Moss and algae also are inadequate. Lichens, however, constitute a high-energy food source (Rochelle 1980). During winter, when the availability of forbs and half-shrubs is reduced by snow, lichens are probably very important sources of energy for wild ruminants. Energy deficits during winter can be offset partially by accumulated fat. The potential limiting role of energy is not a simple, straightforward matter, however, because energy requirements vary with activity and energy intake varies with diet choice.

Requirements for crude protein (N x 6.25) indicate that a minimum N concentration of 0.94 to 1.41 percent is required for maintenance alone, 1.36 to 1.53 percent for maintenance and growth, and 1.47 to 1.74 percent for maintenance and lactation. Forbs and ferns, half-shrubs, and shrubs satisfy these requirements year around, and graminoids satisfy them in early summer. Conifers, feathermoss and beard lichen are inadequate the year around. The foliose lichen *Lobaria,* however, with an N concentration of 3.57 percent, exceeded even the lactation requirements. Rockweed alga could satisfy requirements for maintenance and some growth but not for reproduction.

Table 8—Comparison of mean values of variables measured for Hawk Inlet and Winning Cove study sites

Variable	Hawk Inlet		Winning Cove		Significance [1]	
	Jan.	Mar.	Jan.	Mar.	Jan.	Mar.
	Percent					
NDF	52.5	48.6	51.7	48.0	NS	NS
ADF	36.0	33.6	35.6	32.5	NS	NS
Cellulose	24.4	16.4	22.5	17.9	NS	NS
Lignin-cutin	9.9	13.1	11.5	11.0	NS	NS
12-h IVDMD	32.4	36.0	33.4	37.0	NS	NS
48-h IVDMD	42.9	43.2	41.9	43.9	NS	NS
Observed-Expected DMD	-14.8	-10.2	-11.6	-11.9	NS	NS
Total Ash	5.6	4.6	4.9	4.7	NS	NS
N	1.42	1.88	1.35	1.66	NS	NS
P	.17	.26	.19	.24	0.05	NS
K	.94	1.13	1.03	1.05	NS	NS
Ca	.69	.84	.69	.75	NS	NS
Mg	.26	.21	.24	.26	NS	0.01
Na	.15	.11	.10	.13	NS	NS
	Parts per million					
Cu	6.1	7.5	2.8	7.6	0.001	NS
Mn	1292.6	1451.3	1372.8	1780.2	NS	NS
Fe	193.4	77.5	86.6	62.1	NS	NS
Zn	44.8	38.0	40.4	38.5	NS	NS

[1] Significance is α level at which the mean difference between study sites was statistically different than 0 (paired-sample t-test), NS indicates not significant at $\alpha_{0.05}$.

Table 9—Results of this study compared with those of others [1]

Study and location	Total ash	N	P	Ca	NDF	ADF	Lignin/ cutin	48-h IVDMD
Klein (1965):[2]								
Woronkofski & Coronation Islands, southeastern Alaska	+1.5 (2.2)	+0.80 (0.56)	+0.08 (0.07)	+0.22 (0.40)				
Schoen and Wallmo (1979):[3]								
Admiralty Island, southeastern Alaska		+0.26 (0.23)			-9.3 (6.5)	-2.2 (5.1)	-0.1 (4.0)	
Rose (1982):[4]								
Annette Island, southeastern Alaska		-0.35 (0.58)	-0.03 (0.10)		+2.5 (9.4)	+3.5 (4.8)	+0.9 (5.7)	
Hanley (1980):[5]								
western Washington		-0.02 (0.62)			-3.9 (8.2)	-4.2 (6.2)	-2.2 (3.0)	
Rochelle (1980):[6]								
Vancouver Island, B.C.		0 (0.11)			-11.4 (8.0)	-3.8 (10.1)	+3.7 (3.8)	+4.3 (5.7)

[1] Values are the mean (and standard deviation) difference between this study and others (other study minus this study).
[2] Five comparisons involving *Fauria crista-galli, Carex lyngbyaei, Lysichiton americanum,* and *Vaccinium ovalifolium.*
[3] Eight comparisons involving *Tiarella trifoliata, Rubus pedatus, Cornus canadensis, Coptis aspleniifolia, Tsuga heterophylla, Vaccinium* spp., *Menziesia ferruginea,* and *Usnea* spp.
[4] Twenty comparisons involving *Cornus canadensis, Coptis aspleniifolia, Lysichiton americanum, Maianthemum dilatatum, Rubus pedatus, Streptopus* spp., *Tiarella trifoliata, Vaccinium* spp., and *Usnea* spp.
[5] Fifteen comparisons involving *Tsuga heterophylla, Cornus canadensis, Menziesia ferruginea, Oplopanax horridum, Rubus pedatus, Rubus spectabilis,* and *Maianthemum dilatatum.*
[6] Six comparisons involving *Vaccinium alaskensis* and *Tsuga heterophylla.*

Table 10—Nutrient requirements of beef cattle [1]

	Growing and finishing steers and heifers	Dry pregnant cows	Lactating cows	Mature bulls
	kcal g^{-1}			
Digestible energy	2.2 - 3.1	1.9 - 2.1	1.9 - 2.0	2.0 - 2.3
	Percent			
Crude protein	8.5 - 9.5	5.9 - 8.8	9.2 - 10.9	8.5 - 10.2
Digestible protein	5.0 - 5.6	2.8 - 5.1	5.4 - 6.4	4.8 - 6.3
P	.18 - .70	.18	.18 - .39	.18 - .39
K	.6 - .8	.6 - .8	.6 - .8	.6 - .8
Ca	.18 - 1.04	.18	.18 - .44	.18 - .44
Mg	.04 - .10	.04 - 1.10	.18	.18
Na	.06	.06	.06	.06
	Parts per million			
Cu	4.0	4.0	4.0	4.0
Mn	1.0 - 10.0	20.0	1.0 - 10.0	1.0 - 10.0
Fe	10.0	10.0	10.0	10.0
Zn	20.0 - 30.0	20.0 - 30.0	20.0 - 30.0	20.0 - 30.0

[1] National Research Council. Nutrient requirements of beef cattle. National Academy of Sciences. Washington, D.C. 1976. 56 p.

The National Research Council's requirements for crude protein for beef cattle are based on assumed protein digestibility of 47 to 77 percent, values that are typical for phenolic-free forages. Native forages, especially browses, that are utilized by wildlife, however, may contain appreciable amounts of phenolics or other secondary compounds which reduce protein digestibility. For example, Mould and Robbins (1981) found that fireweed (*Epilobium angustifolium*), which was 12 percent crude protein and 44.2 percent phenolics, had an apparent protein digestibility of 6.1 percent, compared with 68.9 percent digestibility for phenolic-free forages with 12 percent crude protein. The degree to which secondary compounds inhibit digestibility of protein in the Hawk Inlet forages is unknown, but if effects similar to those observed by Mould and Robbins are common, then N availability could be a major nutritional problem for herbivores in southeastern Alaska forests.

Except in forbs and shrub leaves, P concentration was marginal to inadequate in the Hawk Inlet forages. During late summer and fall, it was marginal to inadequate for maintenance and inadequate for lactation in all forage classes. Ca:P ratios were higher than unity (average about 3.3:1, table 5) but not excessively high. High ratios of Ca to P (10:1) reduce the availability of P below what its concentration alone would indicate. Excess Mg may form insoluble P complexes, and excess Mn may form insoluble complexes with Ca (Robbins 1983). Ca levels in the Hawk Inlet forages were more than adequate the year around—about 2 to 8 times minimum requirements. Mg and Mn also were excessive—about 2 to 5 times the minimum requirement for Mg and 12 to 400 times the minimum requirement for Mn.

K levels were marginal to inadequate in conifers the year around and in shrub stems and graminoids during winter. Forbs, half-shrubs, shrub leaves, and algae were more than adequate year around sources. Rockweed alga may be an important source of K during prolonged winter conditions when forbs and half-shrubs are buried with snow. Similarly, forbs would be the major source of Na year around, except when buried with snow. Rockweed alga and graminoids growing along the beach were very high in Na.

Cu concentrations were generally above minimum requirements in all forage classes throughout the year except for conifers and graminoids during winter. Shrubs are potentially the most important source of Cu throughout the year.

Fe concentrations were generally well above minimum requirements in most forages throughout the year. Fe concentrations were especially high in moss, rockweed alga, and graminoids.

Zn levels were above minimum requirements in forbs year around and in shrubs during summer. They were marginal in other forage classes throughout the year and below minimum requirements in conifers in spring and graminoids in fall.

Generally, the Hawk Inlet forages, which did not differ markedly from forages collected elsewhere in southeastern Alaska, appeared to be most limited in digestible energy, P, and probably N. Forbs, half-shrubs, and shrub leaves were consistently the most nutritious forages. Rockweed alga, a common intertidal plant, is a potentially important source of K and Fe when these elements are in short supply in the forest. Nutritional deficiencies are likely to be greatest during winter, especially during periods of snow accumulation, when the availability of forage is restricted and the metabolic costs of locomotion are elevated. During winter, evergreen forbs and half-shrubs are far superior nutritionally to any other forages.

The importance of plant nutrients in limiting herbivore populations varies with specific dietary requirements of species, efficiency of utilizing forage, forage availability, diet choice, and energy requirements. Our identification of digestible energy, N and P as potentially important factors limiting herbivore populations is applicable in a very general sense only.

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Appendix — Results of Chemical Analyses of Hawk Inlet Forages

Neutral Detergent Fiber

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	43.2	42.3	48.7	45.7	42.6	40.1
Dryopteris dilatata	52.0	67.3	48.5	42.1	46.2	42.0
Listera cordata			21.9	25.8		
Lysichiton americanum		15.6	17.8	22.3	27.6	
Maianthemum dilatatum			24.6	26.0		
Moneses uniflora	29.2	29.3	29.9	27.1	27.0	28.9
Streptopus spp.			24.7	29.8		
Tiarella trifoliata	37.0	34.9	31.5	34.0	34.0	35.1
Half-shrubs:						
Cornus canadensis	35.6	36.6	22.8	40.3	30.6	27.9
Rubus pedatus	35.9	34.7	33.7	33.9	32.8	34.3
Vaccinium spp.[1]	55.4	56.4	52.2	55.8	51.9	48.2
Shrubs:						
Menziesia ferruginea—						
Leaves			39.4	33.4	41.7	
Stems	71.9	77.2		79.0	73.8	72.3
Oplopanax horridum—						
Leaves			37.5	30.0	25.5	
Stems			43.7	51.0	60.4	71.9
Rubus spectabilis—						
Leaves			27.0	31.4	32.9	
Stems			53.3	75.2	70.0	
Vaccinium alaskensis—						
Leaves			51.2	55.6	53.2	
Stems	66.6	70.6	56.4	70.3	71.3	64.2
Conifers:						
Picea sitchensis	61.5	58.7	61.2	60.6	57.9	57.1
Tsuga heterophylla	64.3	52.3	48.6	48.5	52.1	48.3
Graminoids:						
Deschampsia caespitosa	70.7		54.9	56.5	78.2	85.3
Carex lyngbyaei			59.2	64.5	68.9	77.6
Lichens:						
Usnea spp.	33.0	21.5	30.2	25.6	33.8	20.8
Moss:						
Rhytidiadelphus loreus	86.3	82.5	80.4	77.7	80.9	82.7
Algae:						
Fucus furcatus	35.7	25.7	26.1	18.3	37.0	24.1

[1] Decumbent, evergreen variety.

Acid Detergent Fiber (sequential)

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	30.4	27.7	30.1	29.8	27.7	26.3
Dryopteris dilatata	37.5	55.6	29.0	33.3	35.8	26.2
Listera cordata			15.9	17.2		
Lysichiton americanum		7.3	11.5	12.8	18.2	18.1
Maianthemum dilatatum			16.9	15.8		
Moneses uniflora	20.2	18.1	14.0	17.2	17.3	
Streptopus spp.			16.9	21.6		
Tiarella trifoliata	27.8	25.9	26.4	24.0	27.6	20.1
Half-shrubs:						
Cornus canadensis	21.7	20.6	18.9	26.6	19.6	21.3
Rubus pedatus	19.1	15.5	17.2	17.6	17.6	17.6
Vaccinium spp.[1]	39.5	34.1	32.7	39.1	35.1	31.8
Shrubs:						
Menziesia ferruginea—						
Leaves			21.5	19.7	27.8	
Stems	50.5	53.6		54.7	49.3	72.3
Oplopanax horridum—						
Leaves			16.2	16.8	17.2	
Stems			30.9	37.3	44.3	53.7
Rubus spectabilis—						
Leaves			11.7	15.2	15.2	
Stems			34.3	49.1	43.6	
Vaccinium alaskensis—						
Leaves			27.9	32.6	31.2	
Stems	50.3	51.6	41.8	53.3	53.1	45.2
Conifers:						
Picea sitchensis	46.1	44.3	44.8	47.1	43.4	40.6
Tsuga heterophylla	51.0	38.5	33.6	36.0	39.2	33.9
Graminoids:						
Deschampsia caespitosa	37.3		28.0	25.2	42.9	48.4
Carex lyngbyaei			26.6	36.8	34.3	41.3
Lichens:						
Usnea spp.	5.8	5.2	4.8	3.6	3.4	4.0
Moss:						
Rhytidiadelphus loreus	58.6	51.1	48.7	53.0	48.4	50.0
Algae:						
Fucus furcatus	29.7	17.9	18.8	12.4	18.5	16.0

[1] Decumbent, evergreen variety.

Cellulose

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	25.6	22.4	25.4	24.4	25.3	21.2
Dryopteris dilatata	19.6	26.2	20.0	17.3	24.3	15.1
Listera cordata			10.0	16.8		
Lysichiton americanum		5.3	9.5	11.4	15.5	
Maianthemum dilatatum			15.4	12.8		
Moneses uniflora	15.0	12.2	10.7	11.9	15.6	14.0
Streptopus spp.			15.6	18.6		
Tiarella trifoliata	18.1	15.0	10.5	15.6	17.8	14.2
Half-shrubs:						
Cornus canadensis	19.0	16.6	7.7	15.8	18.0	11.9
Rubus pedatus	16.0	12.4	14.1	14.4	13.8	13.6
Vaccinium spp.[1]	29.7	19.4	17.9	23.7	23.5	20.3
Shrubs:						
Menziesia ferruginea—						
Leaves			14.8	13.7	16.4	
Stems	31.6	33.6		33.0	31.7	28.1
Oplopanax horridum—						
Leaves			9.4	13.9	12.0	
Stems			20.6	28.0	31.7	37.8
Rubus spectabilis—						
Leaves			8.7	9.2	9.1	
Stems			25.2	32.3	31.9	
Vaccinium alaskensis—						
Leaves			13.9	15.9	16.4	
Stems	29.8	29.6	22.2	31.8	33.0	28.2
Conifers:						
Picea sitchensis	26.7	23.3	26.7	29.3	26.8	27.1
Tsuga heterophylla	32.7	18.1	18.2	20.6	24.2	20.4
Graminoids:						
Deschampsia caespitosa	22.1		23.1	21.3	33.6	37.4
Carex lyngbyaei			22.1	31.0	24.8	30.4
Lichens:						
Usnea spp.	2.5	2.5	2.2	2.0	0.1	0.5
Moss:						
Rhytidiadelphus loreus	35.3	29.0	29.4	31.6	30.2	29.4
Algae:						
Fucus furcatus	13.2	5.9	6.4	5.1	5.3	4.9

[1] Decumbent, evergreen variety.

Lignin/cutin

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
	Percent					
Forbs and ferns:						
Coptis aspleniifolia	4.8	4.6	4.7	5.4	2.3	3.6
Dryopteris dilatata	17.8	28.3	9.0	16.0	11.6	9.7
Listera cordata			6.0	0.4		
Lysichiton americanum		2.0	2.0	1.4	2.7	
Maianthemum dilatatum			1.5	1.4		
Moneses uniflora	3.7	5.4	3.3	5.4	4.6	3.8
Streptopus spp.			1.3	0.5		
Tiarella trifoliata	9.4	10.7	15.9	8.4	9.8	3.9
Half-shrubs:						
Cornus canadensis	1.6	3.1	11.2	10.8	1.4	8.7
Rubus pedatus	3.0	2.8	3.1	3.2	2.9	1.5
Vaccinium spp.[1]	9.8	14.8	14.8	15.3	11.6	10.3
Shrubs:						
Menziesia ferruginea—						
Leaves			6.7	6.0	10.8	
Stems	18.9	19.9		20.8	15.7	15.8
Oplopanax horridum—						
Leaves			6.8	2.9	3.8	
Stems			10.2	9.2	10.5	15.9
Rubus spectabilis—						
Leaves			3.0	6.0	6.2	
Stems			9.1	16.7	11.4	
Vaccinium alaskensis—						
Leaves			14.0	16.7	14.8	
Stems	20.5	16.7	19.6	19.4	17.0	15.4
Conifers:						
Picea sitchensis	19.4	21.1	18.1	17.8	16.1	12.1
Tsuga heterophylla	12.2	20.4	15.4	15.5	14.8	12.4
Graminoids:						
Deschampsia caespitosa	4.4		4.9	3.9	8.2	9.4
Carex lyngbyaei			4.5	5.8	8.4	10.1
Lichens:						
Usnea spp.	2.1	1.4	2.7	1.6	3.3	2.2
Moss:						
Rhytidiadelphus loreus	21.0	21.5	19.3	21.3	17.4	19.8
Algae:						
Fucus furcatus	16.4	12.0	12.4	7.2	12.1	11.1

[1] Decumbent, evergreen variety.

In-Vitro Dry-Matter Digestibility

Forage class and species	Jan. 9		Mar. 20		May 27		Aug. 3		Sept. 29		Nov. 30	
	12 h	48 h	12 h	48 h	12 h	48 h	12 h	48 h	12 h	48 h	12 h	48 h
	Percent											
Forbs and ferns:												
Coptis aspleniifolia	46.9	72.4	50.2	71.2	47.2	61.4	44.0	63.6	44.9	62.7	46.7	70.7
Dryopteris dilatata	35.4	48.2	21.1	21.4	42.3	60.5	24.8	25.1	32.3	48.5	42.3	56.4
Listera cordata					64.7	79.3	57.7	72.7				
Lysichiton americanum			80.6	86.6	61.7	77.0	53.6	75.5	58.0	72.9		
Maianthemum dilatatum					60.8	65.5	66.6	77.4				
Moneses uniflora	54.8	62.2	53.9	70.0	51.1	74.0	50.9	66.1	56.4	69.5	57.1	68.0
Streptopus spp.					60.7	70.1	51.0	69.8				
Tiarella trifoliata	44.1	61.3	44.8	61.6	45.8	54.1	38.8	43.5	42.8	51.7	42.7	54.6
Half-shrubs:												
Cornus canadensis	46.4	75.6	46.5	73.1	51.9	57.3	41.0	58.4	47.2	62.5	49.4	68.7
Rubus pedatus	38.0	54.3	42.2	48.1	39.7	39.5	39.8	46.3	39.6	50.2	43.8	66.8
Vaccinium spp.[1]	37.9	48.4	40.6	48.7	38.9	54.7	31.9	42.4	39.5	53.8	43.5	54.9
Shrubs:												
Menziesia ferruginea—												
Leaves					45.9	62.8	39.3	46.6	34.4	41.6		
Stems	21.2	27.1	16.7	19.0			14.4	21.2	18.4	21.2	21.5	31.3
Oplopanax horridum—												
Leaves					67.0	73.6	55.6	74.0	57.4	72.4		
Stems					62.7	80.1	45.6	56.0	40.4	52.2	24.5	26.5
Rubus spectabilis—												
Leaves					48.2	59.3	47.7	43.3	39.8	35.7		
Stems					34.6	49.7	17.7	24.9	24.0	26.5		
Vaccinium alaskensis—												
Leaves					44.3	51.8	37.0	45.8	40.7	42.4		
Stems	28.0	36.1	24.2	27.8	41.8	49.6	21.2	27.8	23.5	27.1	26.7	36.2
Conifers:												
Picea sitchensis	29.8	30.1	29.1	29.7	24.8	28.3	25.2	28.7	28.7	26.7	28.6	29.7
Tsuga heterophylla	25.5	26.2	31.9	29.8	27.2	33.3	28.8	31.0	31.3	28.9	32.9	33.5
Graminoids:												
Deschampsia caespitosa	29.7	44.6			44.9	43.3	40.7	63.3	22.6	20.1	10.8	18.2
Carex lyngbyaei					50.5	64.3	32.5	42.0	27.7	27.3	13.1	23.9
Lichens:												
Usnea spp.	17.1	20.7	19.3	17.2	19.0	17.0	19.0	15.2	21.6	22.5	16.7	17.1
Moss:												
Rhytidiadelphus loreus	11.2	12.4	13.6	14.5	17.9	15.0	17.8	20.8	16.2	14.1	16.3	18.9
Algae:												
Fucus furcatus	37.9	37.1	42.7	48.4	41.9	33.4	52.9	30.8	47.5	30.2	50.2	37.9

[1] Decumbent, evergreen variety.

Nitrogen

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	1.37	1.50	2.98	1.69	1.73	1.56
Dryopteris dilatata	1.92	1.80	3.63	1.82	1.93	2.14
Listera cordata			2.80	2.22		
Lysichiton americanum		8.00	5.61	5.14	3.78	
Maianthemum dilatatum			2.61	1.45		
Moneses uniflora	2.29	2.46	1.83	1.72	1.97	1.81
Streptopus spp.			4.56	2.39		
Tiarella trifoliata	1.54	1.80	3.27	1.98	1.78	1.86
Half-shrubs:						
Cornus canadensis	1.70	1.58	3.30	2.11	1.66	1.68
Rubus pedatus	1.65	1.92	3.00	1.77	2.04	1.77
Vaccinium spp.[1]	1.50	1.48	1.95	1.20	1.44	1.53
Shrubs:						
Menziesia ferruginea—						
Leaves			3.51	2.00	1.94	
Stems	1.12	.97	2.52	.72	.80	.96
Oplopanax horridum—						
Leaves			5.20	2.69	2.04	
Stems			5.08	.60	.51	1.90
Rubus spectabilis—						
Leaves			2.94	2.04	1.77	
Stems			1.30	.70	.89	
Vaccinium alaskensis—						
Leaves			3.69	2.53	2.14	
Stems	1.50	1.54	2.16	1.10	1.05	1.15
Conifers:						
Picea sitchensis	.95	1.20	1.04	1.05	.89	1.15
Tsuga heterophylla	.84	1.16	.94	1.12	.99	1.03
Graminoids:						
Deschampsia caespitosa	1.14		3.55	1.26	.50	.69
Carex lyngbyaei			2.10	.67	1.02	.86
Lichens:						
Usnea spp.	0.42	0.50	0.36	0.53	0.45	0.35
Moss:						
Rhytidiadelphus loreus	.60	.64	.57	.71	.57	.62
Algae:						
Fucus furcatus	1.23	1.90	1.74	.99	1.23	1.35

[1] Decumbent, evergreen variety.

Phosphorus

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	0.17	0.17	0.40	0.19	0.19	0.19
Dryopteris dilatata	.28	.24	.49	.15	.12	.41
Listera cordata			.48	.36		
Lysichiton americanum		.98	.62	.26	.22	
Maianthemum dilatatum			.38	.21		
Moneses uniflora	.29	.33	.27	.20	.24	.27
Streptopus spp.			.54	.21		
Tiarella trifoliata	.20	.22	.47	.17	.18	.23
Half-shrubs:						
Cornus canadensis	.18	.19	.47	.17	.15	.18
Rubus pedatus	.21	.24	.37	.18	.21	.22
Vaccinium spp.[1]	.15	.17	.19	.12	.16	.17
Shrubs:						
Menziesia ferruginea—						
Leaves			.36	.14	.23	
Stems	.12	.14	.29	.11	.11	.13
Oplopanax horridum—						
Leaves			.91	.22	.17	
Stems			.92	.11	.09	.22
Rubus spectabilis—						
Leaves			.41	.29	.35	
Stems			.37	.11	.12	
Vaccinium alaskensis—						
Leaves			.32	.14	.15	
Stems	.18	.22	.28	.13	.14	.14
Conifers:						
Picea sitchensis	.19	.24	.14	.18	.16	.22
Tsuga heterophylla	.15	.28	.15	.19	.21	.18
Graminoids:						
Deschampsia caespitosa	.14		.29	.16	.06	.06
Carex lyngbyaei			.33	.11	.12	.11
Lichens:						
Usnea spp.	0.08	0.14	0.07	0.12	0.07	0.10
Moss:						
Rhytidiadelphus loreus	.12	.14	.12	.14	.14	.14
Algae:						
Fucus furcatus	.16	.24	.17	.10	.16	.16

[1] Decumbent, evergreen variety.

Potassium

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	1.47	1.44	2.17	1.81	1.62	1.39
Dryopteris dilatata	1.96	1.44	3.95	2.28	2.62	2.30
Listera cordata			3.55	4.43		
Lysichiton americanum		3.73	2.50	1.97	1.75	
Maianthemum dilatatum			2.11	2.68		
Moneses uniflora	1.59	1.67	1.20	1.47	1.54	3.30
Streptopus spp.			5.00	3.64		
Tiarella trifoliata	2.46	2.19	3.16	2.24	2.49	2.55
Half-shrubs:						
Cornus canadensis	1.08	1.00	1.52	1.03	.76	.84
Rubus pedatus	1.45	1.39	1.76	1.25	1.23	1.11
Vaccinium spp.[1]	.78	.74	.89	.56	.78	.72
Shrubs:						
Menziesia ferruginea—						
Leaves			1.60	.81	1.16	
Stems	.33	.37	3.19	.58	.30	.30
Oplopanax horridum—						
Leaves			3.34	1.72	2.23	
Stems			6.30	.43	1.63	.53
Rubus spectabilis—						
Leaves			1.35	1.37	1.17	
Stems			2.83	.53	.54	
Vaccinium alaskensis—						
Leaves			1.14	.56	1.54	
Stems	1.07	.62	1.48	.25	.52	.46
Conifers:						
Picea sitchensis	.64	.62	.54	.68	.56	.90
Tsuga heterophylla	.47	.57	.43	.54	.46	.57
Graminoids:						
Deschampsia caespitosa	.60		2.27	1.76	.44	.24
Carex lyngbyaei			2.56	.77	1.92	.14
Lichens:						
Usnea spp.	0.23	0.29	0.12	0.26	0.21	0.19
Moss:						
Rhytidiadelphus loreus	.47	.50	.36	.45	.42	.40
Algae:						
Fucus furcatus	2.18	2.80	2.59	2.44	2.39	3.70

[1] Decumbent, evergreen variety.

Calcium

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	0.90	0.85	0.37	0.80	0.98	0.82
Dryopteris dilatata	.45	.70	.36	.59	1.05	.47
Listera cordata			.42	.83		
Lysichiton americanum		1.47	.64	1.42	1.77	
Maianthemum dilatatum			.46	.54		
Moneses uniflora	.56	.51	.46	.50	.63	1.30
Streptopus spp.			.64	1.65		
Tiarella trifoliata	1.54	2.58	1.25	1.90	2.25	2.19
Half-shrubs:						
Cornus canadensis	2.94	2.38	1.40	2.97	3.11	2.70
Rubus pedatus	.71	.85	.38	.77	.97	.62
Vaccinium spp.[1]	.77	.82	.88	.76	.88	.97
Shrubs:						
Menziesia ferruginea—						
Leaves			.51	.60	.75	
Stems	.34	.25	.86	.19	.23	.23
Oplopanax horridum—						
Leaves			.14	1.42	2.31	
Stems			.28	.75	1.31	1.18
Rubus spectabilis—						
Leaves			.69	.77	1.22	
Stems			.68	.21	.49	
Vaccinium alaskensis—						
Leaves			.72	1.33	1.60	
Stems	.68	.61	.60	.59	.64	.76
Conifers:						
Picea sitchensis	.24	.32	.39	.45	.42	.35
Tsuga heterophylla	.25	.31	.34	.37	.36	.39
Graminoids:						
Deschampsia caespitosa	.19		.16	.48	.09	.11
Carex lyngbyaei			.16	.07	.66	.55
Lichens:						
Usnea spp.	0.15	0.24	0.41	0.31	0.24	0.36
Moss:						
Rhytidiadelphus loreus	.28	.27	.27	.36	.28	.36
Algae:						
Fucus furcatus	.92	.94	.85	1.94	.77	.94

[1] Decumbent, evergreen variety.

Magnesium

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	0.33	0.31	0.20	0.35	0.31	0.35
Dryopteris dilatata	.40	.26	.30	.61	.45	.46
Listera cordata			.16	.26		
Lysichiton americanum		.22	.21	.25	.25	
Maianthemum dilatatum			.20	.23		
Moneses uniflora	.18	.19	.18	.18	.21	.41
Streptopus spp.			.23	.42		
Tiarella trifoliata	.60	.37	.31	.37	.38	.35
Half-shrubs:						
Cornus canadensis	.53	.43	.37	.61	.52	.45
Rubus pedatus	.61	.53	.36	.48	.48	.40
Vaccinium spp.[1]	.18	.18	.24	.18	.20	.20
Shrubs:						
Menziesia ferruginea—						
Leaves			.38	.42	.41	
Stems	.17	.08	.47	.11	.09	.08
Oplopanax horridum—						
Leaves			.23	.19	.15	
Stems			.23	.14	.20	.16
Rubus spectabilis—						
Leaves			.40	.38	.42	
Stems			.25	.10	.15	
Vaccinium alaskensis—						
Leaves			.33	.45	.38	
Stems	.18	.14	.22	.16	.13	.15
Conifers:						
Picea sitchensis	.07	.08	.08	.08	.08	.09
Tsuga heterophylla	.09	.10	.09	.09	.09	.12
Graminoids:						
Deschampsia caespitosa	.36		.10	.15	.12	.12
Carex lyngbyaei			.15	.09	.17	.14
Lichens:						
Usnea spp.	0.05	0.07	0.06	0.07	0.08	0.05
Moss:						
Rhytidiadelphus loreus	.06	.11	.10	.10	.09	.09
Algae:						
Fucus furcatus	.71	.74	.72	.81	.54	.79

[1] Decumbent, evergreen variety.

Sodium

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Percent			
Forbs and ferns:						
Coptis aspleniifolia	0.09	0.05	0.06	0.06	0.05	0.05
Dryopteris dilatata	.22	.05	.04	.17	.11	.24
Listera cordata			.18	.35		
Lysichiton americanum		.58	.46	1.67	1.31	
Maianthemum dilatatum			.72	.59		
Moneses uniflora	.10	.16	.07	.09	.08	.27
Streptopus spp.			.04	.08		
Tiarella trifoliata	.35	.20	.12	.12	.13	.20
Half-shrubs:						
Cornus canadensis	.07	.04	.09	.06	.02	.03
Rubus pedatus	.03	.11	.04	.07	.07	.12
Vaccinium spp.[1]	.08	.07	.13	.09	.09	.08
Shrubs:						
Menziesia ferruginea—						
Leaves			.09	.52	.80	
Stems	.11	.04	.18	.12	.06	.05
Oplopanax horridum—						
Leaves			.08	.78	.67	
Stems			.20	.25	.51	.12
Rubus spectabilis—						
Leaves			.12	.22	.30	
Stems			.21	.15	.15	
Vaccinium alaskensis—						
Leaves			.18	.41	.31	
Stems	.07	.04	.11	.10	.02	.06
Conifers:						
Picea sitchensis	.06	.06	.04	.08	.11	.05
Tsuga heterophylla	.07	.06	.09	.07	.06	.12
Graminoids:						
Deschampsia caespitosa	1.79		.30	.27	.75	.28
Carex lyngbyaei			.16	1.12	.07	.07
Lichens:						
Usnea spp.	0.13	0.04	0.07	0.07	0.07	0.04
Moss:						
Rhytidiadelphus loreus	.09	.12	.06	.03	.06	.07
Algae:						
Fucus furcatus	2.96	3.68	1.19	3.58	1.83	3.72

[1] Decumbent, evergreen variety.

Copper

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
	Parts per million					
Forbs and ferns:						
Coptis aspleniifolia	6	2	10	2	10	2
Dryopteris dilatata	9	18	20	< 1	6	2
Listera cordata			14	8		
Lysichiton americanum		18	23	5	9	
Maianthemum dilatatum			6	< 1		
Moneses uniflora	10	7	9	3	9	11
Streptopus spp.			16	4		
Tiarella trifoliata	8	3	15	5	5	3
Half-shrubs:						
Cornus canadensis	6	2	12	4	3	4
Rubus pedatus	7	5	14	5	6	6
Vaccinium spp.[1]	7	7	12	4	8	4
Shrubs:						
Menziesia ferruginea—						
Leaves			17	3	10	
Stems	8	10	24	7	13	9
Oplopanax horridum—						
Leaves			25	17	6	
Stems			20	7	5	15
Rubus spectabilis—						
Leaves			6	6	3	
Stems			10	42	3	
Vaccinium alaskensis—						
Leaves			16	12	6	
Stems	11	13	17	15	8	8
Conifers:						
Picea sitchensis	2	7	< 1	6	2	2
Tsuga heterophylla	5	4	1	7	2	2
Graminoids:						
Deschampsia caespitosa	8		4	8	< 1	< 1
Carex lyngbyaei			5	4	1	1
Lichens:						
Usnea spp.	< 1	4	< 1	6	< 1	< 1
Moss:						
Rhytidiadelphus loreus	7	5	5	8	3	3
Algae:						
Fucus furcatus	1	5	< 1	5	< 1	< 1

[1] Decumbent, evergreen variety.

Manganese

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Parts per million			
Forbs and ferns:						
Coptis aspleniifolia	310.2	327.5	131.8	306.9	357.7	521.8
Dryopteris dilatata	1,205.4	350.4	72.6	297.9	408.3	1,674.0
Listera cordata			744.9	1,081.0		
Lysichiton americanum		1,063.0	953.0	364.0	4,799.0	
Maianthemum dilatatum			261.9	785.8		
Moneses uniflora	594.6	736.7	494.8	490.2	625.1	717.5
Streptopus spp.			143.8	448.4		
Tiarella trifoliata	567.9	331.4	127.9	178.0	241.7	484.4
Half-shrubs:						
Cornus canadensis	212.1	233.2	144.0	197.2	213.3	269.9
Rubus pedatus	981.4	1,366.0	763.3	1,082.0	1,507.0	1,726.0
Vaccinium spp.[1]	3,038.0	3,868.0	2,576.0	2,877.0	3,134.0	3,211.0
Shrubs:						
Menziesia ferruginea—						
Leaves			19,620.0	16,370.0	13,980.0	
Stems	4,127.0	6,096.0	19,997.3	3,111.0	4,125.0	5,379.0
Oplopanax horridum—						
Leaves			162.8	281.4	283.1	
Stems			75.8	80.1	97.2	259.1
Rubus spectabilis—						
Leaves			124.9	57.4	72.2	
Stems			39.3	31.9	39.6	
Vaccinium alaskensis—						
Leaves			1,886.0	3,125.0	872.8	
Stems	1,752.0	1,493.0	3,274.0	2,818.0	601.7	2,191.0
Conifers:						
Picea sitchensis	1,577.0	1,666.0	848.2	843.7	1,221.0	1,640.0
Tsuga heterophylla	2,064.0	2,758.0	1,564.0	1,457.0	2,748.0	1,092.0
Graminoids:						
Deschampsia caespitosa	286.1		106.3	559.3	31.8	21.8
Carex lyngbyaei			316.2	39.1	1,095.0	1,332.0
Lichens:						
Usnea spp.	221.1	385.1	133.7	186.1	158.6	240.7
Moss:						
Rhytidiadelphus loreus	1,086.1	943.0	1,336.0	1,261.0	808.1	870.6
Algae:						
Fucus furcatus	24.9	35.6	67.7	31.9	53.3	47.4

[1] Decumbent, evergreen variety.

Iron

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Parts per million			
Forbs and ferns:						
Coptis aspleniifolia	136	39	55	30	39	77
Dryopteris dilatata	187	160	81	28	73	105
Listera cordata			87	82		
Lysichiton americanum		88	104	88	127	
Maianthemum dilatatum			43	36		
Moneses uniflora	637	81	54	42	67	133
Streptopus spp.			76	60		
Tiarella trifoliata	510	67	97	287	108	358
Half-shrubs:						
Cornus canadensis	126	54	55	55	45	117
Rubus pedatus	161	160	50	44	59	119
Vaccinium spp.[1]	103	49	51	27	55	60
Shrubs:						
Menziesia ferruginea—						
Leaves			76	42	68	
Stems	29	17	58	4	21	8
Oplopanax horridum—						
Leaves			82	67	43	
Stems			40	12	14	87
Rubus spectabilis—						
Leaves			41	49	86	
Stems			21	18	19	
Vaccinium alaskensis—						
Leaves			53	58	43	
Stems	17	31	40	23	18	10
Conifers:						
Picea sitchensis	9	20	17	22	45	27
Tsuga heterophylla	115	29	59	72	68	54
Graminoids:						
Deschampsia caespitosa	990		21	110	50	100
Carex lyngbyaei			30	110	42	225
Lichens:						
Usnea spp.	77	51	42	63	60	47
Moss:						
Rhytidiadelphus loreus	434	241	338	371	337	369
Algae:						
Fucus furcatus	120	155	183	153	138	200

[1] Decumbent, evergreen variety.

Zinc

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
			Parts per million			
Forbs and ferns:						
Coptis aspleniifolia	187.3	161.2	118.0	148.0	191.3	260.0
Dryopteris dilatata	84.1	38.7	33.8	10.3	27.8	70.3
Listera cordata			59.6	77.6		
Lysichiton americanum		68.3	45.8	26.6	33.0	
Maianthemum dilatatum			27.2	19.9		
Moneses uniflora	34.4	41.2	32.6	28.2	34.5	38.3
Streptopus spp.			60.1	44.7		
Tiarella trifoliata	80.5	45.2	40.2	35.8	44.1	34.6
Half-shrubs:						
Cornus canadensis	23.1	18.2	33.9	24.6	20.1	16.1
Rubus pedatus	29.3	27.2	36.5	22.4	34.1	42.1
Vaccinium spp.[1]	30.8	30.2	38.0	28.5	34.0	38.6
Shrubs:						
Menziesia ferruginea—						
Leaves			89.2	72.4	98.3	
Stems	32.8	17.6	94.1	25.8	46.9	26.0
Oplopanax horridum—						
Leaves			69.2	32.4	26.2	
Stems			50.8	69.1	98.4	43.2
Rubus spectabilis—						
Leaves			58.2	79.7	108.1	
Stems			134.5	88.0	126.8	
Vaccinium alaskensis—						
Leaves			21.6	17.9	16.4	
Stems	39.2	24.6	60.6	47.7	34.2	30.6
Conifers:						
Picea sitchensis	24.9	15.0	23.0	39.0	34.2	30.5
Tsuga heterophylla	22.9	6.2	11.6	18.3	14.8	11.2
Graminoids:						
Deschampsia caespitosa	34.8		16.5	22.9	12.1	16.5
Carex lyngbyaei			29.7	10.9	21.8	28.1
Lichens:						
Usnea spp.	30.1	21.2	21.3	44.0	25.9	29.2
Moss:						
Rhytidiadelphus loreus	23.0	17.6	16.7	34.1	25.9	25.4
Algae:						
Fucus furcatus	24.7	18.6	19.1	16.2	35.3	19.3

[1] Decumbent, evergreen variety.

Total Ash

Forage class and species	Jan. 9	Mar. 20	May 27	Aug. 3	Sept. 29	Nov. 30
	Percent					
Forbs and ferns:						
Coptis aspleniifolia	5.9	5.2		6.3	6.5	6.3
Dryopteris dilatata	7.1	6.1	10.0	4.4	10.9	8.1
Listera cordata						
Lysichiton americanum		10.0	8.3	11.2	11.7	
Maianthemum dilatatum			7.5	8.1		
Moneses uniflora	6.5	4.8	4.3	4.6	5.4	5.4
Streptopus spp.				11.5		
Tiarella trifoliata	11.6	11.0	9.5	11.0	11.7	11.9
Half-shrubs:						
Cornus canadensis	10.9	9.5	7.6	10.7	11.2	10.4
Rubus pedatus	5.8	5.4	5.1	5.5	6.2	5.3
Vaccinium spp.[1]	4.7	4.0	4.7	4.4	4.9	4.9
Shrubs:						
Menziesia ferruginea—						
Leaves			8.7	7.6	8.5	
Stems	2.2	2.1		2.4	1.8	2.0
Oplopanax horridum—						
Leaves			7.9	9.7	12.2	
Stems			11.9	3.0	6.9	4.4
Rubus spectabilis—						
Leaves			5.0	6.0	6.5	
Stems				2.0	2.6	
Vaccinium alaskensis—						
Leaves			4.7	7.6	8.9	
Stems	3.3	3.2		2.8	2.9	3.2
Conifers:						
Picea sitchensis	2.4	2.0	2.4	2.8	3.0	2.8
Tsuga heterophylla	2.2	2.4	2.1	2.4	2.9	2.7
Graminoids:						
Deschampsia caespitosa	14.3		5.0	6.0	4.8	3.4
Carex lyngbyaei			5.8	4.4	6.7	2.9
Lichens:						
Usnea spp.	1.0	1.2	1.4	1.1	1.4	1.4
Moss:						
Rhytidiadelphus loreus	2.4	2.2	2.2	2.0	2.9	2.6
Algae:						
Fucus furcatus	21.1	24.0	13.3	23.0	16.0	25.0

[1] Decumbent, evergreen variety.

HANLEY, THOMAS A.; McKENDRICK, JAY D. Seasonal changes in chemical composition and nutritive value of native forages in a spruce-hemlock forest, southeastern Alaska. Res. Pap. PNW-312. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 41 p.

Twenty-two forages from Admiralty Island, southeastern Alaska, were monitored bimonthly for one year to assess seasonal changes in their chemical composition: neutral detergent fiber, acid detergent fiber, cellulose, lignin/cutin, in-vitro dry-matter digestibility, total nitrogen, phosphorus, potassium, calcium, magnesium, sodium, copper, manganese, iron, and zinc. Seasonal fluctuations were pronounced but generally paralleled the pulse of plant growth in spring-summer. Only minor differences were found in chemical composition of forages from two study areas and results of this study did not differ greatly from results of other studies in southeastern Alaska and the Pacific Northwest. Forbs, half-shrubs, and shrub leaves were consistently the most nutritious forages, especially during winter. Seasonally low levels of digestible energy, nitrogen, and phosphorus were identified as the most important potential limitations of these forages in meeting the nutritional needs of herbivores.

Keywords: Forage production, nutrient analysis, native plants, phytochemistry, phenology, seasonal variations, Alaska (southeastern), southeastern Alaska, wildlife habitat.

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Research Paper
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Influence of Red Alder on Chemical Properties of a Clay Loam Soil in Western Washington

D. S. DeBell, M. A. Radwan, and J. M. Kraft

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Authors

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Abstract

DeBell, D. S.; Radwan, M. A.; Kraft, J. M. Influence of red alder on chemical properties of a clay loam soil in western Washington. Res. Pap. PNW-313. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 7 p.

Chemical characteristics of mineral soil beneath red alder (*Alnus rubra* Bong.) stands of various ages were studied. Total nitrogen (N) of the 0- to 20-centimeter (0- to 8-inch) soil layer increased with stand age, and pH of both the 0- to 20-centimeter and 20- to 50-centimeter (8- to 20-inch) layers decreased with stand age. Contents of some mineral nutrients accumulated with N in one or the other soil layers. Conversely, exchangeable calcium and magnesium decreased substantially in the 0- to 20-centimeter layer as total N increased and pH decreased. Authors suggest monitoring base status of alder soils and testing base-containing fertilizers in red alder stands.

Keywords: Soil properties (chemical), red alder, *Alnus rubra*, nitrogen accretion, soil pH, mineral soils.

Summary

Chemical characteristics of the 0- to 20-centimeter (0- to 8-inch) and 20- to 50-centimeter (8- to 20-inch) layers of mineral soil under red alder (*Alnus rubra* Bong.) stands, age 0 to 45 years, were studied on the same soil type. The influence of alder on chemical properties was assessed by correlation and linear regression analyses of: (1) total nitrogen (N) content, pH, and mineral nutrient contents with stand age; and (2) mineral nutrient content with total N content and pH. Results were considered significant at $P \leq 0.15$. Total N of the 0- to 20-centimeter layer was positively correlated, and pH of both soil layers was negatively correlated with stand age. None of the mineral nutrients were significantly related to stand age, but many of them were significantly correlated with total N and/or pH. Thus, as N accumulated, total sulfur, exchangeable potassium, and extractable iron, copper, and zinc increased in one or the other soil layers. In addition, exchangeable calcium and magnesium decreased in the 0- to 20-centimeter layer as total N increased and pH decreased. Red alder can enrich N content of forest soils. Amounts of some other nutrients may also be increased in the rooting zone through redistribution, but contents of some important bases may be reduced. Monitoring the base status of alder soils and evaluating the response of red alder stands to base-containing fertilizers are suggested.

Introduction

Red alder (*Alnus rubra* Bong.) is the major hardwood tree species in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) region of the Pacific Northwest. Alder is often considered to be a site-improving species. It is well known for its ability to increase total nitrogen (N) and organic matter of the soil (Bormann and DeBell 1981, DeBell and Radwan 1979, Tarrant and Miller 1963). Accordingly, the species has been recommended for planting on surface mine spoils where low soil fertility is a problem in establishing vegetation. In addition, alder has been suggested as a biological source of N for use in mixtures or crop rotations with conifers.

Effects of alder on soil reaction and levels of nutrients other than N have also been reported, but results have not been consistent. Tarrant (1961), for example, reported that potassium (K), calcium (Ca), and magnesium (Mg) contents of the upper 3 inches (7.6 cm) of soil (including the forest floor) in the Cascade Range of Washington were higher under a mixed stand of red alder and Douglas-fir than under a pure stand of Douglas-fir, although not significantly so. Phosphorus (P) content of the soil did not differ between these stands, and differences in soil pH were not significant. Bollen and others (1967) and Franklin and others (1968) indicated that pH and contents of exchangeable Ca and Mg, and the sum of exchangeable bases were distinctly lower in soil under red alder than in soil under conifers in the Oregon Coast Ranges. There were no significant differences between soils in amounts of exchangeable K, exchangeable sodium (Na), or extractable P, and only small differences in sulfate and available boron (B). Van Cleve and Viereck (1972), working in 0- to 20-year-old thinleaf alder (*Alnus tenuifolia* Nutt.) ecosystems established on flood plain soils in Alaska, reported that pH gradually decreased through age 20. Concentrations of exchangeable K, Ca, Mg, and manganese (Mn), and total P increased markedly during the first 5 years. Little change occurred thereafter except during the last 5 years when K increased and Mg decreased significantly.

The purpose of this investigation was to elaborate on the effects of red alder on N content and pH of the soil and to assess the influence of the species on other essential nutrients in mineral soil.

Materials and Methods

Study Area and Selected Alder Stands

The study area is in the Capitol Forest, southwest of Olympia, Washington, on land administered by the State of Washington Department of Natural Resources. Soils are of the Boistfort series and are very deep, well-drained clay loams formed on Eocene basalt in a mild, wet coastal climate. Overstory vegetation consists primarily of pure and mixed stands of Douglas-fir and red alder. Site index averages about 40 and 30 m, respectively, at 50 years for Douglas-fir and red alder (McMurphy and Anderson 1968). Understory species include swordfern (*Polystichum munitum* (Kaulf.) Presl.), salmonberry (*Rubus spectabilis* Pursh), salal (*Gaultheria shallon* Pursh), vine maple (*Acer circinatum* Pursh), elderberry (*Sambucus* spp.), and Oregongrape (*Berberis aquifolium* Pursh).

Eight stands, similar in soil, aspect, and slope, were selected. Stands were of sufficient size ($>$ 1 ha) to minimize edge effects and, with one exception, were located within an area 2.5 km in radius. Seven of the stands were uniformly stocked with red alder and ranged in age from 9 to 45 years. The eighth stand consisted of the typical forest cover in the general area surrounding the alder stands and was occupied by 40- to 50-year-old Douglas-fir. Mineral soil layers of that stand were assumed to represent the general base-line condition (age 0) for new red alder stands established in the area.

The number of stands used in this study is small, but we were unable to locate additional appropriate stands on the same soil type in the same area.

Sampling and Processing of Mineral Soil

Sampling was done in June 1979. Two perpendicular, 10-m transects were laid out at each of the seven red alder sites, and soil was sampled at equal intervals along the transects. After the forest floor was removed, two layers of mineral soil, 0 to 20 cm and 20 to 50 cm deep, were collected with an aluminum tube. At each site, 20 samples (347 cm^3 each) were collected from the upper soil layer and 8 samples (521 cm^3 each) from the lower soil layer. Soil was composited by layer and site, and samples were airdried at room temperature. Live roots, charcoal fragments, and rocks were removed and discarded. Soil aggregates were crushed with a rolling pin, and the soil was passed through a 2-mm sieve. The $<$2-mm soil was weighed, and subsamples were dried to constant weight at 65 °C to determine moisture content and to prepare the soil for chemical analysis. Subsamples of this soil were dried further at 105 °C, and the ovendry weight of the $<$2-mm soil per hectare was calculated for each layer.

Mineral soil was sampled as described above at four points in each of four locations within the eighth (Douglas-fir) stand and composited to represent the baseline condition.

Chemical Analysis

All chemical analyses were carried out at least in duplicate, and reults were calculated on an ovendry-weight basis.

Soil pH was determined on 1:1 soil-water suspensions by glass electrode. Total N was estimated by the semimicro-Kjeldahl method (Bremner 1965). Minerals determined and analytical methods used were as follows: extractable P (extracted with Bray-Kurtz solution 2 (Bray and Kurtz 1945)) by the molybdenum blue technique (Chapman and Pratt 1961); exchangeable K, Ca, and Mg (extracted with neutral 1N NH_4OAC), and extractable iron (Fe), Mn, copper (Cu), and zinc (Zn) (extracted with diethylene triaminepentaacetic acid (DTPA) according to Lindsay and Norvell (1978)) by standard atomic absorption spectrophotometric methods; and total sulfur (S) and sulfate S (extracted with $Ca(H_2PO_4)_2$ (Fox and others 1964)) by the turbidimetric method of Butters and Chenery (1959).

Statistical Analysis

Correlation analysis and linear regression procedures were used to evaluate relationships of: (a) total N content, pH, and mineral nutrient contents to stand age; and (b) mineral nutrient contents to total N content or soil pH. Relationships were considered significant at $P \leq 0.15$, a level of probability considered appropriate in view of inherent soil heterogeneity and the number of stands used in the study.

Results

Table 1—Chemical characteristics of mineral soil beneath red alder stands in western Washington[1/]

Stand age	pH	N	P	K	Ca	Mg	S	SO_4-S	Fe	Mn	Cu	Zn
Years						*Kilograms/hectare*						
						0- to 20-cm layer						
0	5.52	3030	239	468	1570	296	295	50	121	82	2.4	6.0
9	5.24	3390	240	324	564	74	370	76	126	49	1.5	9.2
18	5.32	2890	58	355	1230	329	270	18	95	37	2.5	7.9
28	5.35	3110	342	432	1310	228	240	0	113	57	2.1	12.7
31	4.90	3330	73	293	568	110	311	27	89	54	1.6	4.4
38	5.30	3590	200	442	1140	236	336	0	117	75	2.7	9.0
42	5.30	3170	266	436	1050	197	270	0	120	67	2.5	9.5
45	4.85	4000	187	294	400	58	386	50	108	44	2.3	24.3
						20- to 50-cm layer						
0	5.45	2550	165	357	1060	251	441	214	112	69	2.2	3.9
9	5.25	4000	262	373	429	67	611	240	116	33	1.8	13.3
18	5.44	3390	48	359	1580	543	424	133	121	39	2.4	14.5
28	5.40	3590	323	483	1380	290	428	174	127	50	2.5	24.8
31	5.03	2330	76	277	443	91	402	140	54	35	.8	2.6
38	5.25	3800	192	459	1130	235	464	162	124	78	2.9	14.3
42	5.29	3740	283	470	1270	299	481	134	144	72	2.7	16.0
45	5.08	3850	154	435	674	133	784	337	112	59	2.4	11.8

1/ Values are means of 2 determinations each, run on the <2-millimeter fraction of mineral soil. Nitrogen (N) and sulfur (S) values represent total content of each element. Other nutrients were determined in soil solutions obtained by extractions with Bray and Kurtz solution No. 2 (1945) for phosphorus (P); 1N neutral NH_4OAC for potassium (K), calcium (Ca), and magnesium (Mg); $Ca(H_2PO_4)_2$ for SO_4-S; and DTPA for iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn).

The pH of mineral soil averaged 5.2 for the upper layer and 5.3 for the lower layer (table 1). Soil pH was negatively correlated with stand age for both the upper and lower layers (table 2).

Total N in the soil to the 50-cm depth ranged from 5580 kg ha^{-1} at age 0 to 7850 kg ha^{-1} at age 45 years. Concentrations of N in the upper layer were much higher than in the lower layer (0.20 to 0.30 percent vs. 0.13 to 0.18 percent), and average content of N was higher at the surface (166 vs. 113 kg ha^{-1} cm^{-1}). Also, total amounts of N in the upper soil layer, but not in the lower, were significantly related to stand age; nitrogen accumulated at a rate of about 12.8 kg ha^{-1} yr^{-1} in the 0- to 20-cm layer. Total N accumulation to a depth of 50 cm was about 27 kg ha^{-1} yr^{-1}.

Table 2—Correlation coefficients (r) between soil chemical characteristics and stand age[1/]

Item	0- to 20-cm layer		20- to 50-cm layer	
	r	P	r	P
pH	-0.58	0.13	-0.57	0.14
Total nitrogen	.58	.13	.36	.38
Extractable phosphorus	-.01	.98	.10	.82
Total sulfur	.12	.78	.29	.48
SO_4-S	-.54	.17	.03	.94
Exchangeable potassium	-.18	.67	.49	.22
Exchangeable calcium	-.42	.31	.02	.95
Exchangeable magnesium	-.36	.38	-.09	.83
Extractable iron	-.23	.59	.08	.84
Extractable manganese	-.14	.74	.33	.43
Extractable copper	.28	.50	.26	.54
Extractable zinc	.52	.18	.29	.48

1/ Correlations are considered significant at $P \leq 0.15$.

Total S trends, especially in the upper layer, were similar to those of total N. Unlike N, however, the average amount of S was slightly higher in the lower layer of soil than in the upper (17 vs. 16 kg ha^{-1} cm^{-1}). In addition, total S of either soil layer was not related to stand age.

Sulfate S was substantially more concentrated in the lower layer than in the upper (average of 6.4 vs. 1.4 kg ha^{-1} cm^{-1}). Extracted P and the bases—K, Ca, Mg, Fe, Mn, Cu, and Zn—did not vary much by layer.

Except for N in the upper layer of mineral soil, contents of other nutrients were not significantly correlated with stand age in either layer ($P > 0.15$ in all cases). The correlation of contents of several mineral nutrients with total N or pH of the respective soil layer, however, was significant as was the negative correlation between soil pH and total N (table 3). Exchangeable Ca and Mg contents of the upper layer of mineral soil were both negatively correlated with total N. Linear regression relationships indicate that decreases of 160 kg ha^{-1} exchangeable Ca and 40 kg ha^{-1} exchangeable Mg are associated with each increase of 100 kg ha^{-1} N. Potassium in the lower layer of mineral soil was positively correlated with total N. Contents of exchangeable Ca, Mg, and K in the upper layer were positively correlated with soil pH; a decrease of 0.1 pH unit is associated with decreases of approximately 100 kg ha^{-1} Ca, 60 kg ha^{-1} Mg, and 20 kg ha^{-1} K. Calcium and Mg contents were also strongly correlated with pH in the lower layer. Iron content of the lower layer was positively correlated with both soil pH and total N, and Cu content of that layer was correlated with total N. Zinc contents of both layers were positively correlated with total N. Total S content of the upper layer was positively correlated with total N and negatively correlated with pH.

Table 3—Correlations between chemical characteristisc of mineral soil and total nitrogen (N) or pH[1]/

Correlation	0- to 20-cm layer		20- to 50-cm layer	
	r	P	r	P
Total N vs. pH	-0.71	0.05	0.04	0.93
vs. phosphorus	.01	.98	.53	.17
vs. total sulfur (S)	.83	.01	.55	.16
vs. potassium (K)	-.46	.26	.74	.04
vs. calcium (Ca)	-.72	.04	.14	.74
vs. magnesium (Mg)	-.74	.03	.04	.93
vs. iron (Fe)	.08	.86	.72	.04
vs. manganese (Mn)	-.13	.77	.16	.71
vs. copper (Cu)	-.06	.89	.64	.09
vs. zinc (Zn)	.72	.04	.73	.04
pH vs. phosphorus	.44	.28	.22	.61
vs.total S	-.56	.15	-.46	.26
vs. K	.85	.01	.25	.55
vs. Ca	.89	.003	.77	.02
vs. Mg	.78	.02	.72	.04
vs. Fe	.54	.17	.61	.11
vs. Mn	.53	.17	.18	.67
vs. Cu	.40	.32	.52	.19
vs. Zn	-.46	.23	.38	.36

[1]/ Phosphorus, K, Ca, Mg, Fe, Mn, Cu, and Zn values represent extracted content of each element. Correlations are considered significant at $P \leq 0.15$.

Discussion and Conclusions

Of all the chemical soil properties studied, only pH and total N of the upper layer of mineral soil were significantly related to stand age. The decrease in soil pH with age parallels previous findings about red alder (Bollen and others 1967, Bormann and DeBell 1981, Franklin and others 1968), and other alder species (Crocker and Major 1955, Van Cleve and Viereck 1972). Such increases in soil acidity with increasing stand age may be related to litter decomposition and nitrification rates which are greater under alder than under stands of other species (Cole and others 1978).

As expected, N was accumulated in the soil under red alder with highest amounts detected in the 0- to 20-cm layer. Nitrogen accretion rates (27 kg $ha^{-1}yr^{-1}$), however, were lower than many of those indicated in the literature for red alder (Bormann and DeBell 1981, DeBell and Radwan 1979, Newton and others 1968, Tarrant and others 1969) and other alder species (Crocker and Major 1955, Van Cleve and others 1971). These previous reports indicate a range of <340 to >300 kg ha^{-1} annually. Such variation in findings, however, is to be expected and may be ascribed to many factors, especially differences in vigor, composition, age, density, and location of the stand; soil fertility; season of sample collection; and methods of sample collection, preparation, and chemical analysis.

None of the mineral nutrients were significantly related to stand age. Present mineral content of soil layers may be influenced by soil mineralogy, previous stand history, present overstory stocking, and understory composition. It is possible that inherent variation among stands in these unaccounted for characteristics was sufficient to mask relationships, if any, of mineral nutrient properties to stand age.

On the other hand, contents of many of the mineral nutrients were strongly correlated with N content or pH of the mineral soil. Because effects of red alder on N accretion and pH have been consistent in nearly all studies, we believe these variables are indices of the cumulative effects of the species on a site. Thus, as N accumulated, total S, exchangeable K, and extractable Fe, Cu, and Zn increased in at least one soil layer. In addition, exchangeable Ca and Mg decreased significantly with increased soil N and acidity. Regression equations suggest that addition of 500 kg N ha^{-1} to the surface layer via a 40-year saw-log rotation of red alder may be accompanied by decreases of 800 kg ha^{-1} of exchangeable Ca and 200 kg ha^{-1} of exchangeable Mg. Some of these bases will undoubtedly be contained in the alder crop and in the understory vegetation (Turner and others 1976). The remainder will probably be leached to greater depth in the soil profile, stimulated by the rapid decomposition, nitrification, and acidification processes beneath alder stands. Potential decreases and leachings of Ca and or Mg are consistent with available literature on red alder (Cole and others 1978, Franklin and others 1968) and other alder species (Van Cleve and Viereck 1972). Furthermore, in pot-culture studies, our unpublished data and experiments by others (Hughes and others 1968) show good response of red alder seedlings to some base-containing fertilizers. Still, more information is needed since the importance of such decreases in soil contents of these mineral nutrients is not known; it will probably depend on many factors, including depth of leaching, inherent soil fertility, rate of mineral weathering, and nutrient requirements of alder and other forest tree species.

This study reaffirms the well-established view that red alder can add significant amounts of N to the soil. Alder, like other hardwoods, may also play an important role in soil development by bringing other nutrients to upper soil layers. Such accumulation and redistribution of nutrients could benefit associated or succeeding forest crops. Red alder, however, will also acidify the soil profile and may lead to reductions of Ca and Mg. Such potential negative effects should not be disregarded. Until more information is available, therefore, the base status [illegible] should be monitored whenev[illegible] grown for long periods. W[illegible] testing nonnitrogenous fertilizers on alder under field condition[illegible] we believe, is necessary if red alder is to be grown in pure or n[illegible] maximum yield without [illegible] on soil productivity.

Acknowledgments

We thank James E. Wilcox, USDA Forest Service, for assisting in statistical analyses and the U.S. Department of Energy, Biomass Energy Technology Division, Short Rotation Woody Crops Program, for funds that helped support this work.

English Equivalents

1 centimeter = 0.3937 inch
1 millimeter = 0.03937 inch
1 hectare = 2.471 acres
1 kilogram per hectare
= 1.1206 pounds per acre
(9/5°C) + 32 = °F

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Chemical characteristics of mineral soil beneath red alder (*Alnus rubra* Bong.) stands of various ages were studied. Total nitrogen (N) of the 0- to 20-centimeter (0- to 8-inch) soil layer increased with stand age, and pH of both the 0- to 20-centimeter and 20- to 50-centimeter (8- to 20-inch) layers decreased with stand age. Contents of some mineral nutrients accumulated with N in one or the other soil layers. Conversely, exchangeable calcium and magnesium decreased substantially in the 0- to 20-centimeter layer as total N increased and pH decreased. Authors suggest monitoring base status of alder soils and testing base-containing fertilizers in red alder stands.

Keywords: Soil properties (chemical), red alder, *Alnus rubra,* nitrogen accretion, soil pH, mineral soils.

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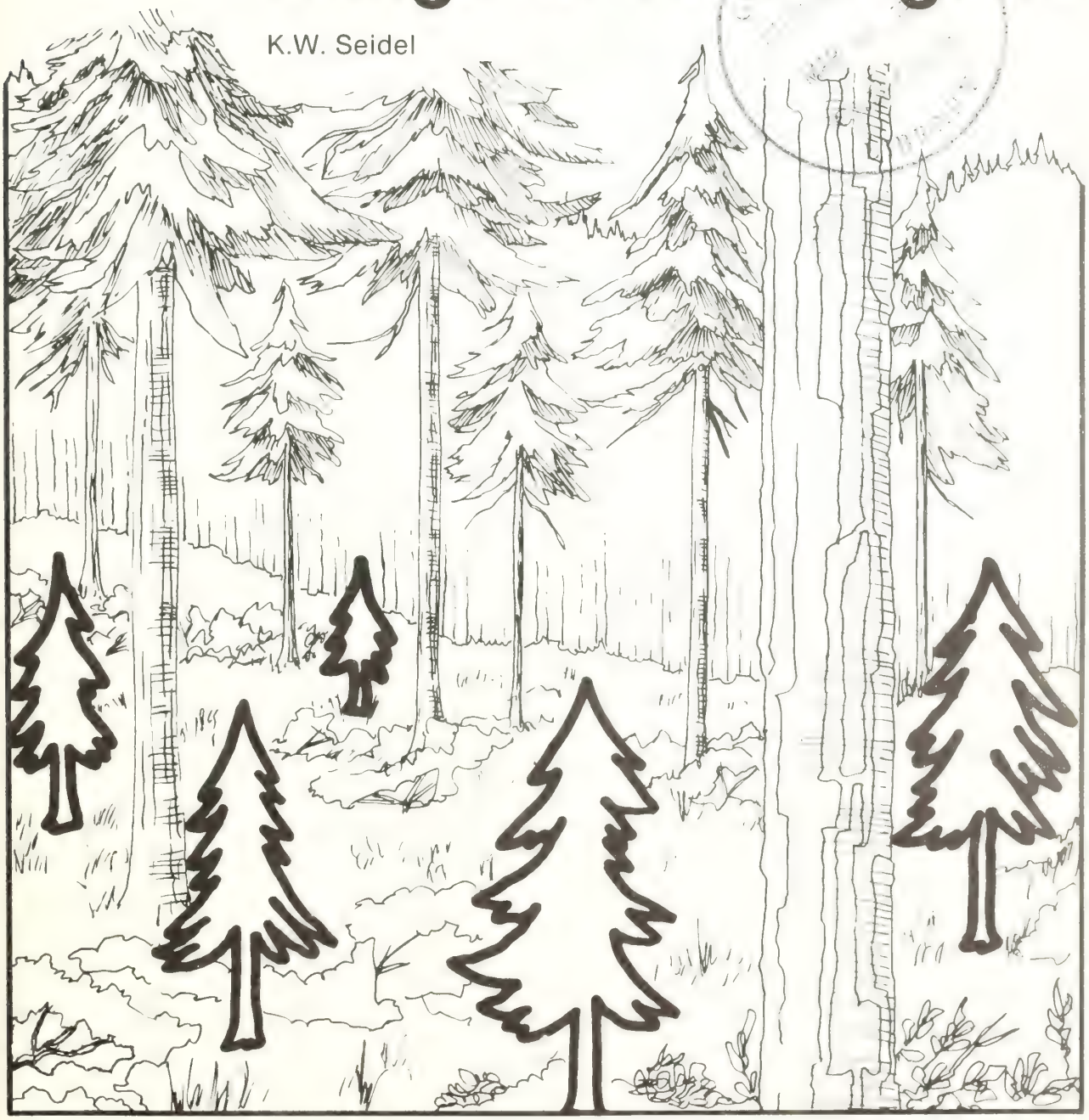
Regeneration in Mixed Conifer and Douglas-Fir Shelterwood Cuttings in the Cascade Range of Washington

K.W. Seidel



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Abstract

Seidel, K. W. Regeneration in mixed conifer and Douglas-fir shelterwood cuttings in the Cascade Range of Washington. Res. Pap. PNW-314. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 17 p.

A survey of shelterwood cuttings in mixed conifer and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in the Cascade Range in Washington showed that, on the average, shelterwood units were adequately stocked with a mixture of advance, natural postharvest, and planted reproduction of a number of species. Shelterwood cuttings in the Douglas-fir type had abundant regeneration, whereas those in the mixed conifer type had generally adequate stocking but fewer seedlings. Much of the understocking appeared to be related to a nonuniform overstory, lack of advance reproduction, or high elevation.

Keywords: Shelterwood cutting method, regeneration (stand), regeneration (natural), regeneration (artificial), Cascade Range—Washington, Washington (Cascade Range).

Summary

Regeneration of shelterwood cuttings in mixed conifer and Douglas-fir forests at midelevation of the Cascade Range in Washington was surveyed for an overview of the status of reforestation and to identify key environmental factors influencing establishment of seedlings. Plots were randomly located in shelterwood units harvested from 1970 to 1976 in a Douglas-fir and a mixed conifer forest type in the Cascade Range.

On the average, shelterwood units in the mixed conifer type were stocked with about 1,572 seedlings or saplings per acre (all origins), whereas the Douglas-fir units contained an abundance of regeneration (7,111 per acre). Average milacre stocking of mixed conifer was 56 percent; of Douglas-fir, 89 percent. About 73 percent of the reproduction in the mixed conifer type and 96 percent in the Douglas-fir type were of natural postharvest origin. Planted seedlings accounted for less than 10 percent of the regeneration in both types but were present on a greater number of stocked milacres than their small numbers might suggest because of their uniform distribution.

Greater stocking was generally associated with increasing density of the overstory. Other factors, such as aspect, slope, and elevation, varied in their relationship to stocking depending on species and forest type. Understocking in the mixed conifer type appeared to be related to a nonuniform overstory, lack of advance reproduction, or high elevation. Equations for predicting stocking were derived for several species in both types, but, because of the large amount of unexplained variation, they serve only as crude estimates of possible stocking.

Usually, residual stand density after the seed cut should be reduced to the minimum level at which an acceptable amount of regeneration will be established. It appears that 6 to 8 trees per acre in the Douglas-fir type and about 25 trees per acre in the mixed conifer type distributed uniformly over the area should result in adequate stocking on most units.

Planting is generally unnecessary after the seed cut in the Douglas-fir type because of prolific natural regeneration. In the mixed conifer type, planting is needed if residual stand density is much below 25 trees per acre or where aggressive understory vegetation could quickly occupy the seedbed. Blowdown of the residual overstory was greater in the mixed conifer type—about 1.3 trees per acre compared with 0.5 tree in the Douglas-fir type. The risk of blowdown can be reduced by leaving trees that are fully crowned dominants or codominants (the most windfirm and also the best producers of seed) and by locating cutting boundaries where the risk of windthrow is low.

Introduction

The shelterwood method was used to harvest timber in many upper slope mixed conifer forests in eastern Oregon and Washington during the late 1960's and 1970's. This method was a way of modifying the harsh environmental conditions found on many high elevation clearcuts that cause regeneration to fail. Some of these shelterwood units are now old enough for regeneration to be established, but success has varied considerably—from units well stocked with a number of species to units with very little regeneration.

The presence of these units in various plant communities provided an opportunity to evaluate the regeneration and to relate various environmental factors to its establishment. This paper reports the results of a 1981 field survey of regeneration on two Ranger Districts in the Wenatchee and Gifford Pinchot National Forests, the factors affecting its establishment, and survival of the residual overstory.

Objectives

The purposes of this study were to: (1) quantitatively evaluate regeneration on the shelterwood units, (2) determine survival of residual overstories during the regeneration period, and (3) identify environmental factors associated with the presence or absence of regeneration.

Specific objectives were to estimate:

1. Success of regeneration in terms of stocking percentage and density (number per acre).
2. Species composition of the regeneration.
3. Stocking of regeneration of preharvest (advance) and postharvest (natural and planted) origins.
4. The relationship between regeneration and some measurable environmental variables, such as elevation, aspect, slope, and overstory density.
5. Survival of the residual overstories.

Study Areas

Study areas were located in the Cascade Range of Washington (fig. 1). A plant community classification has not been completed for this area. Therefore, plots were located in two forest cover types based on overstory tree species. These two types are: (1) The Douglas-fir type where Douglas-fir is the primary species (Mount Adams District of the Gifford Pinchot National Forest) and (2) the mixed conifer type where no single overstory species was dominant (Naches District of the Wenatchee National Forest).1/

The major tree species found in these types are Douglas-fir, grand fir, western hemlock, mountain hemlock, and western larch. The understory vegetation is generally well developed, and many species are present. Primary species in the mixed conifer type are bearberry, prince's pine, big huckleberry, common snowberry, shinyleaf spirea, pinegrass, Idaho fescue, sky lupine, twinflower, woollyweed, rattlesnake plantain, and American vetch.

Principal understory species in the Douglas-fir type are vine maple, thimbleberry, baldhip rose, big huckleberry, boxwood, and beargrass.

Soils supporting the mixed conifer forest type are Cryorthents and Cryandepts (Snyder and Wade 1973). Cryorthents are generally very deep soils (12 feet or more) underlain by igneous or pyroclastic bedrock. These soils are derived from glacial till and are generally well drained; they have a sandy loam texture. Cryandepts are somewhat shallower soils (1 to 10 feet) derived from residuum or colluvium. Surface soils are sandy loams or loams, and subsoils vary from gravelly loams to silty clays. Both soil types are considerably influenced by volcanic ash or loess. Soils in the Douglas-fir type are similar. They generally range from 2 to more than 12 feet in depth and are derived from till, colluvium, and residuum with local areas of ash, cinders, and pumice. Texture of the surface soil varies from coarse sand to loamy sand.

1/ Scientific names of plants are listed on page 11.

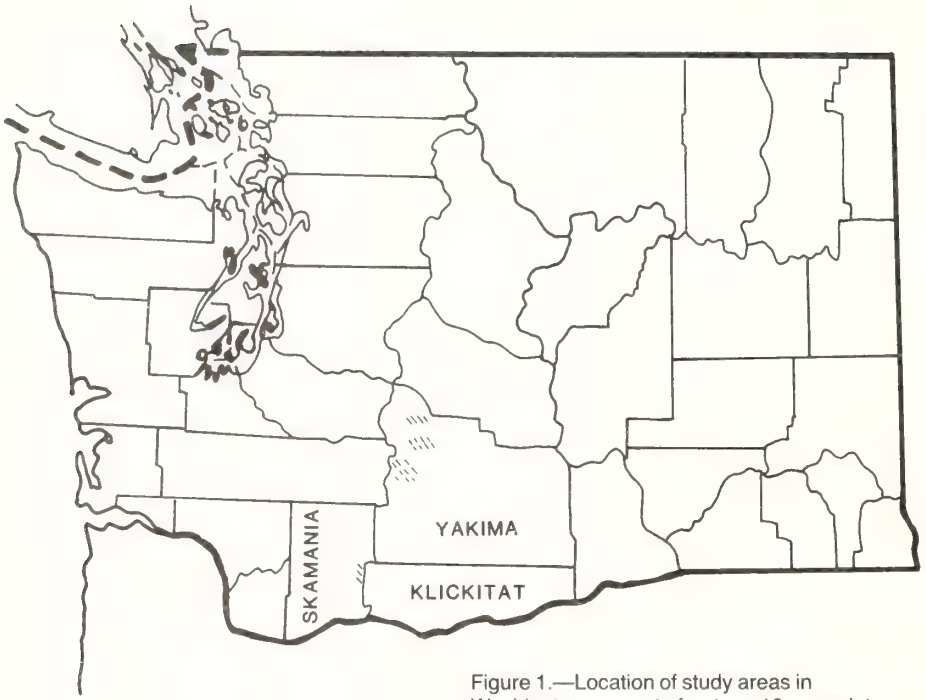


Figure 1.—Location of study areas in Washington; seven to fourteen 10-acre plots were sampled in each of the four areas.

Some characteristics of the shelterwoods sampled are given in table 1. The average elevation of mixed conifer plots was about 1,500 feet higher than elevation of the Douglas-fir plots (4,525 vs. 3,079 feet). The major difference in the overstory between the two types was species composition and tree size. On the average, plots in the Douglas-fir type contained fewer but larger trees and more basal area than plots in the mixed conifer type.

In the Douglas-fir type, the primary overstory species was Douglas-fir, comprising 65 percent of the trees (fig. 2). Other species present were grand fir—10 percent, western hemlock—6 percent, mountain hemlock—6 percent, Engelmann spruce—4 percent, Pacific silver fir—5 percent, plus small numbers of western redcedar and western larch.

Table 1—Mean and range of some characteristics of shelterwood units sampled in 2 timber types in the Cascade Range of Washington

Characteristic	Unit of measure	Douglas-fir type (14 plots)		Mixed conifer type (26 plots)	
		Mean	Range	Mean	Range
Elevation	Feet	3,079	2,750-3,750	4,526	3,000-5,300
Slope	Percent	5.5	0-19	7.5	0-18
Age	Years	7.2	4-10	5.9	5-11
Residual overstory:					
Trees per acre	Number	15.4	9-27	19.4	9-32
Average diameter	Inches	33.5	27-41	20.4	12-29
Basal area	Square feet	66.1	25-114	38.3	18-57
Crown closure	Percent	37.7	17-57	26.0	11-35
Seedbed:					
Mineral soil	Percent	12.3	2-28	1/	1/
Litter	Percent	52.3	36-67	1/	1/
Slash	Percent	14.9	6-32	14.9	7-30
Understory vegetation:					
Forbs	Percent	13.7	2-34	10.0	1-32
Shrubs	Percent	24.4	1-69	7.2	0-30
Grasses and sedges	Percent	10.2	0-69	19.8	2-40

1/ Values not given because of errors caused by ash deposits on some plots from eruption of Mount St. Helens.

Methods

Figure 2.—Shelterwood unit in the Douglas-fir type.

Mixed conifer plots exhibited greater diversity of species, and no single species dominated the overstory. Grand fir and Douglas-fir each accounted for about 23 percent of the overstory; western larch and mountain hemlock each comprised 16 percent. Other species were Engelmann spruce—9 percent, ponderosa pine—6 percent, and western hemlock—3 percent. Pacific silver fir, western redcedar, lodgepole pine, and western white pine were also present but only in small numbers, each amounting to less than 1 percent of the overstory.

Slash on all plots in the Douglas-fir type was piled by machine and burned after the seed cut. In the mixed conifer type, slash was piled and burned on 23 of 26 plots; on 2 plots, unmerchantable material was yarded; on 1 plot, slash was not treated.

Survey Design and Plot Selection

Douglas-fir and mixed conifer types were considered separate populations. A record of shelterwood units harvested in 1976 or earlier in these timber types in east-side Ranger Districts of the Gifford Pinchot and Wenatchee National Forests was obtained from the USDA Forest Service Regional Office (Pacific Northwest Region) in Portland, Oregon. Only units at least 5 years old were considered suitable for sampling so that reproduction would have had time to become established. Plot size was 10 acres; thus, all shelterwood units of this size or larger and at least 5 years old were potential plots.

I estimated that a total of about 40 plots could be sampled during the available time. Therefore, 26 plots were selected at random from the total number (196) in the mixed conifer type and 14 from the total (65) in the Douglas-fir type, resulting in a sampling intensity of about 13 and 22 percent, respectively. Candidate sample plots were rejected if the shelterwood unit was direct seeded to trees or if it had been converted to nonforest uses.

Collection of Data

A grid of 25 sample points was centrally located on each 10-acre plot, spaced at 66-foot intervals. At each sample point, three concentric subplots (1-milacre, 4-milacre, and 0.0785-acre) were examined for presence of regeneration, associated environmental variables, and condition of residual overstory.

Ranger District records and field observations provided plot information on elevation, timber type, date of harvest, slash treatment method and year of treatment, species planted and year of planting, subsequent cultural treatments, and general notes on size, growth, and distribution of regeneration, or damage.

On each 1-milacre subplot, the total number of seedlings of each species was counted and recorded by origin—preharvest (advance) or postharvest (subsequent). Trees of postharvest origin were divided into 1- and 2-year-old seedlings from natural seed fall, seedlings 3 years old and older from natural seed fall, and planted trees. On each 4-milacre subplot, the species and origin (advance, natural postharvest, or planted) of the seedling or sapling most likely to dominate the subplot because of its size and vigor were recorded.[2/] Four-milacre subplots were used for data on dominant trees to reduce the probability of unstocked subplots. On each 0.0785-acre subplot, species and diameter at breast height (d.b.h.) were recorded for overstory trees, including trees that died during the regeneration period, and windthrown trees.

Planted trees were identified from information on species planted, date of planting, and spacing. In shelterwoods where survival was high, regular rows of planted trees were clearly visible. Identification of planted trees was less certain when survival was low, but counting branch whorls to check the age of a tree helped to identify planted trees.

The following environmental factors associated with each 1-milacre subplot were observed and recorded:[3/] aspect; slope; condition of the seedbed (mineral soil, litter, slash); degree of burn; understory vegetation (forbs, shrubs, grasses); residual overstory density (basal area and percent crown closure); and presence or absence of animal damage.

[2/] A dominant tree was selected on the basis of its height, general vigor as indicated by live crown ratio and past height growth, and species.

[3/] See appendix for details of procedures of measuring and coding the environmental factors.

Analysis of Data

To illustrate the present status of reforestation, I summarized data in tables showing seedling numbers and stocking percentage of milacre subplots by species and origin for the forest types. To determine the relationship between regeneration and environmental variables, I used stepwise multiple regression procedures to fit linear equations of the form $Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots b_n X_n$ to the data. Dependent (Y) variables used were percentages of milacre subplots stocked and number of seedlings per acre of the various species and origins, and the independent (X) variables were the environmental variables given in the appendix.[4/] Curvilinear equations of the form $Y = a + b\,(1 - e^{-cx})^d$ were used to relate individual independent variables to percentage of stocked milacres because in some cases they described the relationship more realistically than did a linear model.

4/ Subplots were considered stocked if they contained at least one seedling.

Regeneration Stocking and Density

Regeneration on shelterwood units in the mixed conifer type, for all species and origins combined, was generally satisfactory in terms of average seedling numbers and stocked milacres (1,572 per acre and 56 percent stocked) (table 2). The Douglas-fir shelterwood units contained an abundance of regeneration. Seedling density (all classes) averaged 7,111 per acre, and 89 percent of the milacre subplots were stocked.

The majority of the regeneration in both timber types consisted of seedlings of natural origin that became established after the seed cut. This was especially true in the Douglas-fir type where 96 percent of the regeneration was of natural postharvest origin compared with 73 percent in the mixed conifer type. Advance reproduction was a negligible component (less than 1 percent) of the regeneration in the Douglas-fir type, but in the mixed conifer type it accounted for about 19 percent. This difference can be attributed to the fact that there was little advance reproduction present before logging in the Douglas-fir shelterwoods and that nearly all of it was destroyed in the slash treatments that were applied uniformly over the units. In contrast, the residual overstory stocking was more irregular in the mixed conifer units, and distribution of advance reproduction was clumpy, occurring mostly in areas undisturbed by logging or slash treatment activity.

One- and two-year-old seedlings were generally present in considerable numbers, accounting for 40 percent of the reproduction in the Douglas-fir type and 26 percent in the mixed conifer type. In spite of their large numbers, these young seedlings do not play as great a role as other components of the regeneration because of their small size and high mortality rates. The primary effect of these seedlings was to increase density of the regeneration rather than to greatly increase stocking percentages. In the Douglas-fir type, for example, milacre stocking was increased more than 12 percent on only 7 percent of the plots even though the young seedlings made up 40 percent of the regeneration.

Table 2—Average stocking percent and number of seedlings per acre of all species on shelterwood units in 2 timber types in the Cascade Range of Washington, by class of reproduction 1/

Class of reproduction	Douglas-fir type			Mixed conifer type		
	Number of plots	Mean ± S.E. 2/	Range	Number of plots	Mean ± S.E. 2/	Range
			Stocking percent			
Advance	14	3.1 ± 0.9	0-12	26	13.5 ± 2.6	0-44
Postharvest:						
1- and 2-year-old seedlings	14	58.0 ± 6.8	16-96	26	19.5 ± 3.3	0-60
3-year-old and older seedlings	14	78.0 ± 3.6	52-96	26	30.0 ± 3.5	4-64
Planted seedlings	12	28.7 ± 5.6	0-56	21	14.7 ± 2.8	0-44
All classes except 1- and 2-year-old seedlings	14	83.7 ± 3.2	56-96	26	47.4 ± 2.4	12-76
All classes	14	89.1 ± 3.0	56-100	26	56.0 ± 3.9	24-88
			Number per acre			
Advance	14	37 ± 11	0-160	26	294.0 ± 70	0-1,520
Postharvest:						
1- and 2-year-old seedlings	14	2,840 ± 540	480-6,240	26	406.0 ± 82	40-1,480
3-year-old and older seedlings	14	4,003 ± 750	1,320-12,200	26	746.0 ± 136	40-3,280
Planted seedlings	12	270 ± 64	0-680	21	156.0 ± 31	0-480
All classes except 1- and 2-year-old seedlings	14	4,271 ± 737	1,400-12,280	26	1,166.0 ± 141	240-3,400
All classes	14	7,111 ± 954	3,960-15,500	26	1,572.0 ± 196	400-4,840

1/ Based on 1-milacre subplots.

2/ S.E. = standard error.

Planted seedlings made up only 4 to 9 percent of reproduction. Although present in small numbers, planted seedlings are distributed almost uniformly over units which results in a greater percentage of stocked milacres than might be expected by their small numbers (table 2).

Establishment of natural regeneration in these shelterwood units was both profuse and rapid after the seed cut. Even though the average age of these units is only 6 to 7 years, the largest single component of the regeneration is natural postharvest seedlings 3 years old and older (table 2). For seedlings of this age to be present, adequate seed must have fallen within 1 to 3 years after logging. Establishment of seedlings within a few years after the seed cut appears to be common not only in these forest types but also in mixed conifer forests in the Cascade Range and Blue Mountains in Oregon (Seidel 1979, Seidel and Head 1983).

For a greater insight into the levels of stocking and seedling density among the shelterwood units, plots were grouped according to the number and percentage that attained specific levels of stocking or density (table 3). The considerable difference in establishment of regeneration between the two timber types is apparent. If 40-percent stocking of milacre quadrats is considered satisfactory, then all the Douglas-fir units meet this standard compared with 69 percent of the mixed conifer units. Based on seedling numbers, all the Douglas-fir shelterwoods had at least 700 seedlings per acre in contrast to only 77 percent of the mixed conifer units. Lack of regeneration is not a problem on the Douglas-fir shelterwoods; rather, some of the units are overstocked. Five units had more than 7,000 seedlings per acre with a maximum density of 15,520 on one plot. Although large numbers of seedlings are present now, overstocking after the seed cut is not an immediate problem because some regeneration will be lost when the residual overstory is removed. Stocking level control should begin promptly after the final removal cut, however, in areas where regeneration is excessively dense.

Table 3—Proportion of shelterwood units stocked at various levels with 3-year-old and older advance and postharvest regeneration in 2 timber types in the Cascade Range of Washington 1/

Timber type	Stocking			Trees per acre		
	At least	Plots	Proportion of total	At least	Plots	Proportion of total
	Percent	Number	Percent	Number	Number	Percent
Douglas-fir (14 plots)	20	14	1.00	200	14	1.00
	40	14	1.00	400	14	1.00
	60	13	.93	700	14	1.00
	80	10	.71	1,000	14	1.00
	100	7	.50	2,000	12	.86
				3,000	9	.64
				5,000	4	.29
Mixed conifer (26 plots)	20	25	.96	200	26	1.00
	40	18	.69	400	24	.92
	60	10	.38	700	20	.77
	80	0	0	1,000	12	.46
				2,000	4	.15
				3,000	1	.04

1/ Based on 1-milacre subplots.

Species Composition of Regeneration

The mixture of species in the regeneration in both types was similar to that of the overstory. Douglas-fir and grand fir were the two most abundant species in the Douglas-fir type, found on 78 and 44 percent of the milacres, respectively (table 4). Stocking of the other nine species in the reproduction was much less, ranging from 0.3 percent for ponderosa pine to 8.6 percent for mountain hemlock.

In the mixed conifer type, grand fir and Douglas-fir were also the two major species, but stocking of the other species (except for western and mountain hemlocks) was greater and no single species was found on the majority of milacres. The most noticeable shift in species composition was fewer hemlock seedlings and greater numbers of western larch, ponderosa pine, and lodgepole pine than in the Douglas-fir type.

Dominant Species

In addition to estimates of the abundance and distribution of the regeneration, a classification of seedling vigor or size is desirable to give some idea of the species most likely to predominate as the stand develops. In both types, Douglas-fir and grand fir were the two dominant species, and regeneration of natural postharvest origin was dominant on the majority of the stocked subplots (table 5). Because of their greater height and uniform distribution over the units even though present in small numbers, planted seedlings (primarily Douglas-fir) were dominant on about one-third of the stocked subplots in the Douglas-fir type and on about one-fourth of the stocked subplots in the mixed conifer type.

It is evident from these data that, although Douglas-fir and grand fir were the two major species in the regeneration in both types, the mixed conifer type has more species occupying dominant positions in contrast to the Douglas-fir type where all species other than Douglas-fir and grand fir were dominant on 3 percent or less of the stocked subplots.

Table 4—Average stocking of advance and postharvest regeneration on shelterwood units in 2 timber types in the Cascade Range of Washington, by species 1/

Species	Douglas-fir type, postharvest seedlings 2/				Mixed conifer type, postharvest seedlings 2/			
	Advance seedlings	3-year-old and older	1- and 2-year-old	All classes	Advance seedlings	3-year-old and older	1- and 2-year-old	All classes
	Stocking percent + S.E. 3/							
Grand fir	0.6 ± 0.4	38.9 ± 7.3	14.9 ± 4.5	44.3 ± 7.6	9.8 ± 2.3	15.4 ± 2.7	7.8 ± 1.6	29.5 ± 3.5
Pacific silver fir	.9 ± .5	1.7 ± 1.0	.6 ± .6	2.9 ± 1.6	1.1 ± .5	0 ± --	.3 ± .2	1.2 ± .5
Douglas-fir	.9 ± .6	70.3 ± 6.3	46.3 ± 8.3	78.0 ± 6.2	.5 ± .3	12.9 ± 3.0	8.9 ± 2.5	19.4 ± 3.8
Western hemlock	.6 ± .6	4.0 ± 1.9	7.8 ± 2.8	7.9 ± 2.9	.3 ± .3	.3 ± .2	.3 ± .3	.8 ± .6
Mountain hemlock	.6 ± .4	3.5 ± 1.3	8.4 ± 3.2	8.6 ± 3.3	.9 ± .5	2.5 ± 1.0	.8 ± .5	3.8 ± 1.4
Western redcedar	0 ± --	1.1 ± .7	0 ± --	1.1 ± .7	0 ± --	.3 ± .3	0 ± --	.3 ± .3
Engelmann spruce	0 ± --	5.4 ± 2.2	2.0 ± 1.2	5.7 ± 2.3	.3 ± .2	5.8 ± 1.6	1.2 ± .5	7.1 ± 1.8
Western white pine	0 ± --	3.4 ± 1.6	.3 ± .3	3.7 ± 1.6	0 ± --	2.5 ± .8	2.2 ± .9	4.6 ± 1.5
Western larch	0 ± --	2.9 ± 2.3	.3 ± .3	3.1 ± 2.3	.8 ± .3	6.9 ± 2.1	1.7 ± .9	8.6 ± 2.7
Ponderosa pine	0 ± --	.3 ± .3	0 ± --	.3 ± .3	.2 ± .2	3.8 ± 1.2	.8 ± .4	4.6 ± 1.6
Lodgepole pine	0 ± --	2.3 ± 1.2	0 ± --	2.3 ± 1.2	0 ± --	2.9 ± 1.6	1.1 ± .6	3.4 ± 1.7

1/ Based on 1-milacre subplots.

2/ Includes natural and planted regeneration.

3/ S.E. = standard error.

Table 5—Stocked subplots on shelterwood units, in 2 timber types in the Cascade Range of Washington, by species and origin of dominant seedlings 1/

Origin of seedlings	Grand fir	Pacific silver fir	Douglas-fir	Western hemlock	Mountain hemlock	Western redcedar	Engelmann spruce	Western white pine	Western larch	Ponderosa pine	Lodgepole pine	Total
	Percent											
Douglas-fir type:												
Advance	0.6	1.2	1.8	0.6	--	--	--	--	--	--	--	4.2
Natural postharvest	16.5	1.8	39.2	.6	1.8	--	1.2	0.6	1.5	0.3	--	63.5
Planted	7.9	--	23.8	--	--	--	.6	--	--	--	--	32.3
Total	25.0	3.0	64.8	1.2	1.8	--	1.8	.6	1.5	.3	--	100.0
Mixed conifer type:												
Advance	14.3	1.5	2.1	--	2.4	--	1.1	--	1.1	.6	0.2	23.3
Natural postharvest	14.3	.6	7.1	--	3.0	0.2	3.0	1.1	9.8	6.6	5.3	51.0
Planted	--	--	17.3	--	--	--	6.2	--	1.1	1.1	--	25.7
Total	28.6	2.1	26.5	--	5.4	.2	10.3	1.1	12.0	8.3	5.5	100.0

1/ Based on 4-milacre subplots; 1- and 2-year-old seedlings included.

Relation of Stocking and Density to Environmental Factors

For an assessment of the influence of observed environmental variables on density and stocking of regeneration and their relative importance, correlation coefficients were computed between each environmental variable and stocking percent and density of regeneration. The results of these analyses are presented in tables 6 and 7 in the appendix.

The effect of these variables on stocking and density of regeneration depends on the species as well as on the timber type. In the Douglas-fir type, for example, aspect showed a significant negative correlation to density of regeneration, indicating that regeneration was generally less abundant on more northerly aspects (table 7). Although significant, this relationship is based on plots' having a limited range of aspects and slopes, with some nearly flat. Regardless of aspect, however, regeneration was adequate on all plots. In the mixed conifer type, there was little relationship of aspect to stocking or density of regeneration.

Grass cover was negatively correlated to stocking and density of regeneration in the Douglas-fir type, but there was little relationship between grass and reproduction in the mixed conifer type (tables 6 and 7). Although a strong negative correlation exists between grass and regeneration in the Douglas-fir type, it appears that this is due to a single shelterwood unit with heavy grass cover and poor stocking; there is little relationship among the remaining units. Nevertheless, grass—especially sod-forming species—can offer severe competition to young seedlings (Dimock 1981). In both forest types, stocking of grand fir regeneration showed a significant positive correlation to woody understory vegetation (table 6) and to variables such as crown closure, basal area, or residual trees per acre which indicate a shadier microsite. This agrees with observations of many young grand fir seedlings growing under shrubs.

In general, the effect of these variables on stocking and density of regeneration in the Douglas-fir and mixed conifer types is summarized as follows:

Douglas-fir type

Increased stocking	Decreased stocking	Little relationship
More basal area	More northerly aspect	Elevation
More crown closure	Greater slope	Gopher damage
More overstory trees per acre	More grass	Burn
More litter	Animal damage	Forbs
	Greater age of unit	Shrubs
		Average diameter of overstory
		Mineral soil
		Slash

Mixed conifer type

Increased stocking	Decreased stocking	Little relationship
Greater crown closure	Higher elevation	Aspect
More overstory trees per acre	More forbs	Slope
Greater age of unit	Greater average diameter of the overstory	Slash
More shrubs		Burn
Animal damage		Grass
		Basal area
		Gopher damage

With few exceptions, most of the correlations appear reasonable. The positive correlation of animal damage to regeneration in the mixed conifer type was not expected, although a similar relationship was found in partial cuts in the Blue Mountains of northeastern Oregon (Seidel and Head 1983). Perhaps the additional disturbance of the seedbed by livestock and big game may have resulted in a more favorable seedbed; or consumption of grasses, forbs, and shrubs may have reduced competition from this understory vegetation. Although it is possible that increased numbers of seedlings could result from activity of livestock and big game, the net effect is likely to be negative because of damage to the regeneration that results in reduced height growth and poor form.

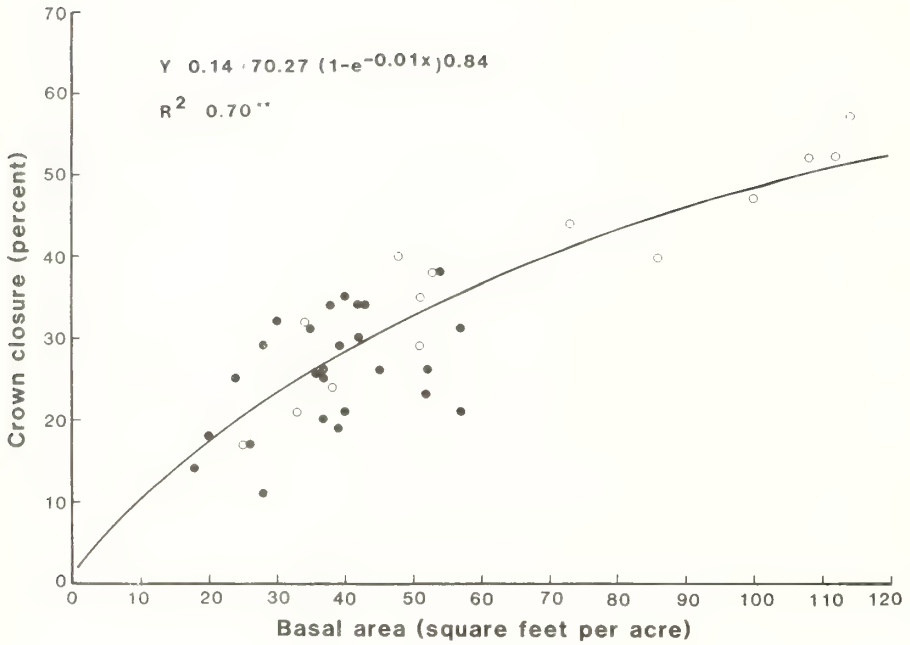


Figure 3.—Relationship between basal area and crown closure of residual overstory for all shelterwood plots in both Douglas-fir and mixed conifer types in the Cascade Range of Washington; ** means significant at the 1-percent probability level.

As expected, a good relationship was found between overstory crown closure and basal area ($R^2 = 0.7$) (fig. 3). The single curve fits the data from both forest types and is similar to the relationship for mixed conifer shelterwoods in the Cascades in Oregon (Seidel 1979). This curve should be useful for obtaining estimates of crown closure from basal area which is more easily measured.

Residual Stand Density and Regeneration

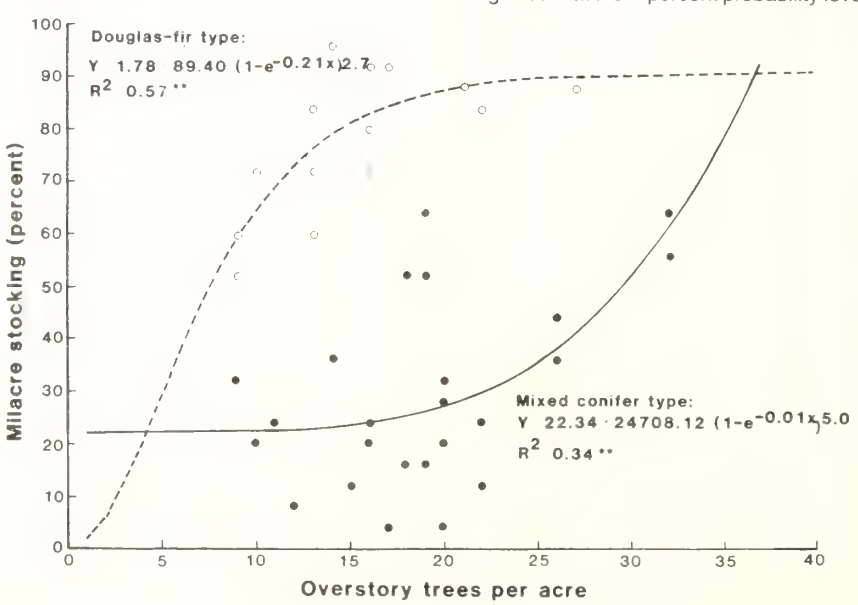
In the Douglas-fir type, overstory basal area, crown closure, and residual trees per acre all showed significant positive correlations to stocking and density of regeneration (tables 6 and 7); in the mixed conifer type, only residual trees per acre was significantly correlated with regeneration (all species combined).

The relationship of greater stocking of 3-year-old and older natural reproduction to the number of overstory trees as density increases is illustrated in figure 4. The equation for the Douglas-fir type is a better predictor of stocking, accounting for 57 percent of the variation in stocking, compared with 34 percent for the mixed conifer equation. Because of the considerable amount of unexplained variation, these curves are not accurate enough for precise estimates of expected regeneration, but they do give some insight into the minimum number of overstory trees needed to obtain adequate stocking. Because of the abundant natural regeneration in the Douglas-fir type, the residual overstory required is much less than in the mixed conifer type where regeneration is not as plentiful. If, for example, 40-percent stocking of milacre plots is considered satisfactory, then 6 to 8 trees per acre in the Douglas-fir type compared with about 25 trees per acre in the mixed conifer type should result in adequate stocking on most units.

Prediction Equations

Reliable equations to assess the potential for regeneration of cutting units before harvest would be useful. To derive such equations, I used only variables that remain unchanged or nearly so over time or that can be adjusted to preharvest values. Thus, variables such as grasses, forbs, and shrubs that tend to increase after harvest were excluded. The variables used were elevation, aspect, slope, slash, degree of burn, basal area, crown closure, number of overstory trees per acre, and average diameter. The amount of slash and degree of burn do not remain completely unchanged over time, but the change is negligible within the timespan of this study. Basal area, trees per acre, and average diameter were adjusted to values immediately after the seed cut by adding data from dead and down trees.

Figure 4.—Relationship between overstory trees per acre and milacre stocking of 3-year-old and older natural regeneration in the Douglas-fir and mixed conifer types in the Cascade Range of Washington; ** means significant at the 1-percent probability level.



In the Douglas-fir type, the equation predicting milacre stocking of 3-year-old and older natural regeneration accounted for 75 percent of the variation with only two variables (crown closure and slash) (table 8 in the appendix). The sign (+ or -) of terms appearing in these equations does not always agree with the sign associated with the correlation coefficients but depends on the particular combination of variables in any equation; for example, basal area appears as a negative term when crown closure is already in the equation but as a positive term when entered first.

The equations for the mixed conifer type accounted for 39 to 68 percent of the variation in stocking (table 9 in the appendix). In the western larch equation, crown closure appeared as a negative term (as in table 6), indicating that the establishment of the shade-intolerant larch was reduced by a heavier overstory in contrast to more shade-tolerant species, such as grand fir, which were favored by greater stand densities.

Because of the considerable amount of unexplained variation associated with these equations and because they were not tested on an independent set of data, they should not be considered accurate predictors of expected regeneration after shelterwood cutting but only crude estimates of possible stocking. The best use of these equations may be to rank proposed shelterwood units on their potential for the establishment of natural regeneration in order to assign supplemental planting.

Influence of Planted Seedlings

Planted seedlings assume greater importance in units where there are fewer natural seedlings. Thus, in the Douglas-fir type where the prolific natural regeneration resulted in all units being well stocked (over 75 percent), planting after the seed cut is unnecesssary. On the other hand, in the mixed conifer type, planting did contribute to satisfactory stocking on some units because of uniform distribution. For example, if a 40-percent stocking of milacre quadrats is considered satisfactory, then planting increased stocking above this level on 19 percent of the units in the mixed conifer type.

The need for planting depends on the forest type or plant community. The best use of planting immediately after the seed cut is in shelterwood units in the mixed conifer type where residual stand density is much below 25 trees per acre or where aggressive understory vegetation could quickly occupy the seedbed. In the Douglas-fir type, the most efficient use of planting is to fill in any holes in the regeneration resulting from removal of the residual overstory.

Overstory Mortality

Mortality of the residual overstory after the seed cut was about three times greater in the mixed conifer type than in the Douglas-fir type. In the mixed conifer type, about 11 percent of the overstory was lost—an average of 1.3 trees per acre blown down and 0.8 tree per acre standing dead. In the Douglas-fir type, about 4 percent of the trees were lost—0.5 tree per acre to windthrow and 0.1 per acre standing dead.

Using the shelterwood system in unmanaged old-growth stands can result in problems with blowdown because trees growing at high densities have not developed the windfirmness needed to resist strong winds after heavy partial cuts. The risk of blowdown can be reduced by leaving dominant or codominant, full-crowned trees that are the most windfirm and also the best seed producers (Gordon 1973). In addition, using guidelines for locating cutting boundaries and for identifying topographic situations where the risk of blowdown is high can decrease the mortality from windthrow. Alexander (1964) prepared such guidelines for spruce-fir forests in Colorado which may be useful in the mixed conifer forests at high elevations in Oregon and Washington.

Conclusions and Recommendations

Results of this survey show that, in the Douglas-fir type, the use of the shelterwood system resulted in satisfactory natural regeneration in all units. In the mixed conifer type, natural regeneration was not as abundant, but the combination of advance reproduction, natural regeneration, and planted seedlings resulted in adequate stocking on about three-fourths of the units. Understocking in this type appeared to be related to at least one of the following factors: nonuniform overstory, lack of advance reproduction, and high elevation.

The shelterwood system should be used only in stands where the risk of excessive blowdown is not extreme and where the stand contains enough healthy dominant and codominant trees to provide a residual overstory spaced uniformly over the area. In such stands, a residual overstory of 6 to 8 trees per acre in the Douglas-fir type and about 25 trees per acre in the mixed conifer type is recommended as sufficient for adequate natural regeneration. Adjustments to residual overstory density can be made for various aspects, slopes, or elevations by use of the prediction equations. These equations provide only very rough estimates of expected stocking and are probably best used to obtain a ranking of potential shelterwood units for natural regeneration rather than an accurate estimate.

Advance reproduction that is sufficiently vigorous to respond to release can be an important component of regeneration in the mixed conifer type, especially in areas where animal damage could be a problem. Saving the advance reproduction requires skillful application of logging techniques designed to preserve the established regeneration, such as those suggested by Gottfried and Jones (1975), and good coordination between timber and fuels management staffs.

Planting after the seed cut is generally not needed in the Douglas-fir type because abundant natural regeneration is quickly established. Planting is most useful here as a supplemental practice to replace natural regeneration destroyed or damaged during the final overstory removal. In the mixed conifer type, shelterwood units should be planted only if residual stand density is not sufficient to obtain natural regeneration or if seedbeds are expected to be invaded quickly by grasses, forbs, or shrubs. If natural regeneration has not resulted in adequate stocking after 3 or 4 years in unplanted units, the residual overstory should be removed and units planted except in frost pockets where seedlings will not survive or grow without the thermal protection of some overstory.

Common and Scientific Names of Plants [5/]

Trees:

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Vine maple	*Acer circinatum* Pursh
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western larch	*Larix occidentalis* Nutt.
Western redcedar	*Thuja plicata* Donn ex D. Don
Western white pine	*Pinus monticola* Dougl. ex D. Don

Shrubs:

Baldhip rose	*Rosa gymnocarpa* Nutt.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Big huckleberry	*Vaccinium membranaceum* Dougl. ex Hook.
Boxwood	*Pachistima myrsinites* (Pursh) Raf.
Common snowberry	*Symphoricarpos albus* (L.) Blake
Prince's pine	*Chimaphila umbellata* (L.) Bart.
Shinyleaf spirea	*Spiraea betulifolia* Pall.
Thimbleberry	*Rubus parviflorus* Nutt.

Forbs:

American vetch	*Vicia americana* Muhl. ex Willd.
Beargrass	*Xerophyllum tenax* (Pursh) Nutt.
Rattlesnake plantain	*Goodyera oblongifolia* Raf.
Sky lupine	*Lupinus nanus* Dougl.
Twinflower	*Linnaea borealis* L.
Woollyweed	*Hieracium scouleri* Hook.

Grasses:

Idaho fescue	*Festuca idahoensis* Elmer
Pinegrass	*Calamagrostis rubescens* Buckl.

[5/] Sources for nomenclature: trees (Little 1979); shrubs, forbs, and grasses (Garrison and others 1976).

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot/acre = 0.2296 square meter/hectare
1 tree/acre = 2.47 trees/hectare

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Appendix

Independent (X) variables used in regression analyses:

1. **Elevation.**—The average elevation of the plot to the nearest 10 feet as measured with an altimeter.
2. **Aspect.**—One of eight compass points measured on each subplot. The method proposed by Day and Monk (1974) was used to code the aspect, and the following values were assigned to compass directions: N - 14; NE - 15; E - 11; SE - 7; S - 3; SW - 2; W - 6; NW - 10. Average coded value of the 25 subplots was used in analyses.
3. **Slope.**—Percentage slope of each subplot was measured with a clinometer and coded as follows: 0-9 percent, 0; 10-19 percent, 1; 20-29 percent, 2; 30-39 percent, 3; etc. Average coded value of subplots was used.
4. **Mineral soil.**—The percentage of each subplot containing mineral soil was estimated, coded in the same way as slope values, and averaged.
5. **Litter.**—The percentage of each subplot covered with litter was estimated, coded in the same way as slope values, and averaged.
6. **Slash.**—The percentage of each subplot covered with slash was estimated, coded in the same way as slope values, and averaged.
7. **Degree of burn.**—Estimated on each subplot and coded as: none, 0; light, 1; medium, 2; heavy, 3. Averaged coded value was used in analyses. Degree of burn is defined as: None—no visible effect of fire; light—fire charred the surface of the forest floor but did not remove all the litter layer; medium—fire removed all the litter layer and some of the duff; heavy—fire removed all the litter and duff and imparted a color to the mineral soil.
8. **Forbs.**—The percentage of each subplot covered with forbs was estimated, coded in the same way as slope values, and averaged.
9. **Shrubs.**—The percentage of each subplot covered with shrubs was estimated, coded in the same way as slope values, and averaged.
10. **Grasses and sedges.**—The percentage of each subplot covered with grasses and sedges was estimated, coded in the same way as slope values, and averaged.
11. **Basal area.**—The overstory basal area at each subplot was measured with a 10-factor angle gage and averaged for use in analyses.
12. **Crown closure.**—The overstory crown closure was measured with a spherical densiometer at each subplot by Strickler's (1959) method. Average value of the 25 subplots was used in analyses.
13. **Overstory trees per acre.**—The numbers of standing overstory trees (living and dead) and blown down trees were recorded on 0.0785-acre subplots at each of the 25 sample points, averaged, and converted to a per-acre basis.
14. **Overstory average diameter.**—The diameters at breast height of living and dead standing trees and blown down trees on each 0.0785-acre subplot were measured to the nearest inch and averaged.
15. **Animal damage.**—The presence or absence of damage such as browsing or trampling by animals other than gophers (primarily deer, elk, or cattle) was recorded for each subplot. The percentage of subplots showing such damage was used in the analyses.
16. **Gopher activity.**—The presence or absence of gopher activity as indicated by mounds was recorded for each subplot. The percentage of subplots showing such activity was used in the analyses.
17. **Age of unit.**—The number of years since the seed cut was made was recorded for each unit.

Table 6—Significant correlation coefficients (r) between environmental variables and stocking percent of regeneration on shelterwood units in 2 timber types in the Cascade Range of Washington 1/

Species or origin	Aspect	Slope	Elevation	Mineral soil	Litter	Slash	Burn 2/	Forbs	Shrubs	Grass	Basal area	Crown closure	Residual trees per acre	Quadratic mean diameter	Animal damage	Gopher damage	Age of unit
Douglas-fir type:																	
All regeneration	-	+	+	+	-	+	+	-	+	-0.95**	+	+	+	-	-0.69**	-	-
All natural regeneration	-	-	-	+	+	-	+	-	+	-.79**	+	0.53*	+	-	-.56*	+	-
All postharvest regeneration	-	-	+	+	+	-	+	-	+	-.76**	+	.46	+	-	-.53*	+	-
Natural postharvest	-	-	-	+	+	-	+	-	+	-.73**	+	.49	+	-	-.52*	+	-
3 years old and older	-	-0.47	-	+	0.45	-	-	+	+	-.59*	0.53*	.74**	0.63*	+	-	+	-
All grand fir	-	-.48	-	+	+	+	-	0.53*	0.69**	-	.79**	.77**	.65*	-	-	+	-0.63*
All Douglas-fir	-	-	+	+	+	-	-	-	-	-.84**	+	+	+	-	-.47	-	-
Mixed conifer type:																	
All regeneration	+	+	-			+	-	-.39*	.37	-	+	-	.50**	-0.46*	+	-	+
All natural regeneration	+	+	-			+	-	-.33	+	-	+	+	.50**	-.55**	+	-	+
All postharvest regeneration	+	-	-			+	-	-	+	+	-	-	.53**	-.35	+	-	+
Natural postharvest	+	-	-			+	-	-	+	+	-	+	.56**	-.47*	+	+	+
3 years old and older	+	-	-0.35			+	-	-	+	+	-	-	.51**	-.34	-.34	+	+
1 and 2 years old	+	-	-			-	+	-	+	+	-	+	.33	-.50**	-.40*	+	+
All grand fir	+	-	-.34			0.33	+	-	.39*	-	-	+	.49**	-.60**	+	-	.39*
Postharvest grand fir	+	+	-.47*			+	+	-	+	+	+	+	.65**	-.43*	+	+	+
All Douglas-fir	-	-	-.55**			+	0.34	+	+	.33	-	+	.54**	-.33	.37	+	+
Postharvest Douglas-fir	-	-	-.53**			+	.34	+	+	.33	-	+	.51**	-	+	+	-
All ponderosa pine	-0.42*	+	-.36			-	-	.33	-	.50**	-	+	+	-	-	+	-
All larch	+	-	+			-	-	-.40*	-	-	-	-.54**	-	+	-	-	+
All spruce	.37	-	.35			-	-	-.47*	-	-	-	-.59**	-	-	+	-	.53**
All white pine	+	+	-			+	+	-	+	-	-	-	+	-.37	.40*	-	.81**

1/ Correlation coefficients with no asterisk are significant at the 10-percent probability level; 1 asterisk, 5-percent level; 2 asterisks, 1-percent level. Plus and minus signs indicate a nonsignificant positive or negative correlation.

2/ Pile and burn.

Table 7—Significant correlation coefficients (r) between environmental variables and density of regeneration on shelterwood units in 2 timber types in the Cascade Range of Washington 1/

Species or origin	Aspect	Slope	Elevation	Mineral soil	Litter	Slash	Burn 2/	Forbs	Shrubs	Grass	Basal area	Crown closure	Residual trees per acre	Quadratic mean diameter	Animal damage	Gopher damage	Age of unit
Douglas-fir type:																	
All regeneration	-0.47	-	-	-	0.53*	-	-	-	+	-0.46	+	0.54*	0.57*	-	-	-	-
All natural regeneration	-.48	-	-	-	.53*	-	-	+	+	-	+	.53*	.56*	-	-	-	-
All postharvest regeneration	-.48	-0.45	-	-	.53*	-	-	-	+	-.46	+	.53*	.57*	-	-	-	-
Natural postharvest	-.48	-.45	-	-	.54*	-	-	+	+	-	+	.53*	.56*	-	-	-	-
3 years old and older	-.60*	-.55*	-	-	+	+	-	+	+	-	0.61*	.65*	.71**	-	-	+	-0.57*
All grand fir	-.65*	-.47	-	-	+	+	-	0.49	0.54*	-	.70**	.70**	.78**	-	-	+	-.49
All Douglas-fir	-	-	+	+	+	-	-	-	-	-.49	+	+	+	+	-	-	-
Mixed conifer type:																	
All regeneration	+	+	-			+	-	-	+	-	-	-	.42*	-0.56**	+	-	+
All natural regeneration	+	+	-			+	-	-	+	-	-	+	.43*	-.59**	+	-	+
All postharvest regeneration	+	-	-0.36			-	-	-	+	+	-	-	.41*	-.50**	0.42*	+	+
Natural postharvest	+	+	-.37			+	-	-	+	+	-	-	.43*	-.55**	.42*	+	+
3 years old and older	+	+	-.34			+	-	-	+	+	-	-	.39*	-.48*	.35	+	+
1 and 2 years old	+	-	-.32			+	+	-	+	+	-	+	.37	-.52**	.42*	+	+
All grand fir	+	+	-			0.33	+	-	+	-	-	+	.40*	-.57**	+	-	.63**
Postharvest fir	+	+	-.42*			.36	+	+	+	+	-	.38*	.72**	-.43*	+	+	-
All Douglas-fir	-	-	-.45*			-	+	.35	+	.36	+	.52**	.50**	-.34	+	+	+
Postharvest Douglas-fir	-	-	-.42*			-	+	.39*	+	.38*	+	.53**	.51**	-	+	+	-
All ponderosa pine	-.42*	+	-.32			-	-	+	-	.45*	-	+	+	-	+	+	-
All larch	+	-	.33			-	-	-.37	-	-	+	-.47	-	+	-	-	-
All spruce	.3*	-	+			-	-	-.35	-	-	-	-.62	-	+	+	-	.51**
All white pine	+	+	+			+	-	-	+	-	-	-	+	-	+	-	+

1/ Correlation coefficients with no asterisk are significant at the 10-percent probability level; 1 asterisk, 5-percent level; 2 asterisks, 1-percent level. Plus and minus signs indicate a nonsignificant positive or negative correlation.

2/ Pile and burn.

Table 8—Prediction equations for milacre stocking on shelterwood units in a Douglas-fir type in the Cascade Range of Washington

Dependent variable	Equation	Variation explained, R^2	Standard error of estimate, $S_{y \cdot x}$
		-------Percent--------	
1- and 2-year-old seedlings	= -5.63 + 8.50 (slash) + 4.50 (crown closure) -1.79 (basal area)	0.55	19.5
3-year-old and older seedlings	= 57.63 + .90 (crown closure) - 9.08 (slash)	.75	7.4
All natural regeneration	= -26.52 + 1.83 (crown closure) - 0.42 (basal area) + 0.022 (elevation) + 21.72 (burn)	.64	9.02
All regeneration	= -425.73 + 1.88 (crown closure) + 0.083 (elevation) - 5.16 (slope) + 9.14 (age) + 3.56 ($\bar{x}$ diameter) + 8.58 (slash)	.66	8.2
All grand fir	= 183.63 + 1.59 (basal area) - 19.37 (slash) -2.82 ($\bar{x}$ diameter) - 6.25 (trees/acre) - 2.88 (aspect)	.83	14.8
All Douglas-fir	= -86.74 + 3.03 (crown closure) - 0.81 (basal area) + 0.034 (elevation)	1/ .44	19.7

1/ Not significant.

Table 9—Prediction equations for milacre stocking on shelterwood units in a mixed conifer type in the Cascade Range of Washington

Dependent variable	Equation	Variation explained, R^2	Standard error of estimate, $S_{y \cdot x}$
		-- Percent --	
1- and 2-year-old seedlings	= 19.77 - 1.92 ($\bar{x}$ diameter) + 5.27 (age) + 0.82 (trees/acre) - 0.82 (aspect)	0.39	14.3
3-year-old and older seedlings	= -44.13 + 2.15 (trees/acre) + 8.93 (age) + 8.41 (slope) - 0.006 (elevation)	.60	12.2
All natural regeneration	= -29.32 - 2.74 ($\bar{x}$ diameter) + 0.69 (basal area) + 10.43 (age) + 1.80 (trees/acre) + 15.70 (slope)	.68	13.9
Natural postharvest	= -43.87 + 2.50 (trees/acre) + 9.76 (age) - 1.39 ($\bar{x}$ diameter) + 9.16 (slope)	.61	14.8
All regeneration	= -40.22 + 2.02 (trees/acre) + 10.79 (age) + 15.49 (slope) - 1.72 ($\bar{x}$ diameter) + 0.45 (basal area)	.68	12.5
All grand fir	= 20.22 - 1.11 ($\bar{x}$ diameter) + 1.19 (trees/acre) + 8.21 (slope)	.53	14.0
Postharvest grand fir	= 22.18 + 1.13 (trees/acre) - 0.007 (elevation) + 4.43 (slash)	.51	10.7
All Douglas-fir	= 46.54 - 0.012 (elevation) + 1.15 (trees/acre) + 29.24 (burn)	.49	14.9
All ponderosa pine	= 33.22 - 0.67 (aspect) - 0.85 ($\bar{x}$ diameter) - 4.80 (slash) + 3.71 (slope)	.46	6.6
All larch	= 51.93 - 1.23 (crown closure) - 38.75 (burn) - 5.31 (slope)	.52	10.1

Seidel, K. W. Regeneration in mixed conifer and Douglas-fir shelterwood cuttings in the Cascade Range of Washington. Res. Pap. PNW-314. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983.** 17 p.

A survey of shelterwood cuttings in mixed conifer and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in the Cascade Range in Washington showed that, on the average, shelterwood units were adequately stocked with a mixture of advance, natural postharvest, and planted reproduction of a number of species. Shelterwood cuttings in the Douglas-fir type had abundant regeneration, whereas those in the mixed conifer type had generally adequate stocking but fewer seedlings. Much of the understocking appeared to be related to a nonuniform overstory, lack of advance reproduction, or high elevation.

Keywords: Shelterwood cutting method, regeneration (stand), regeneration (natural), regeneration (artificial), Cascade Range—Washington, Washington (Cascade Range).

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U.S. Department of Agriculture
Forest Service
Pacific Northwest Forest and Range Experiment Station
Research Paper PNW-315
February 1984

Some Effects of Predaceous Birds and Ants on the Western Spruce Budworm on Conifer Seedlings

Robert W. Campbell, Clinton E. Carlson,
Leon J. Theroux, and Thomas H. Egan

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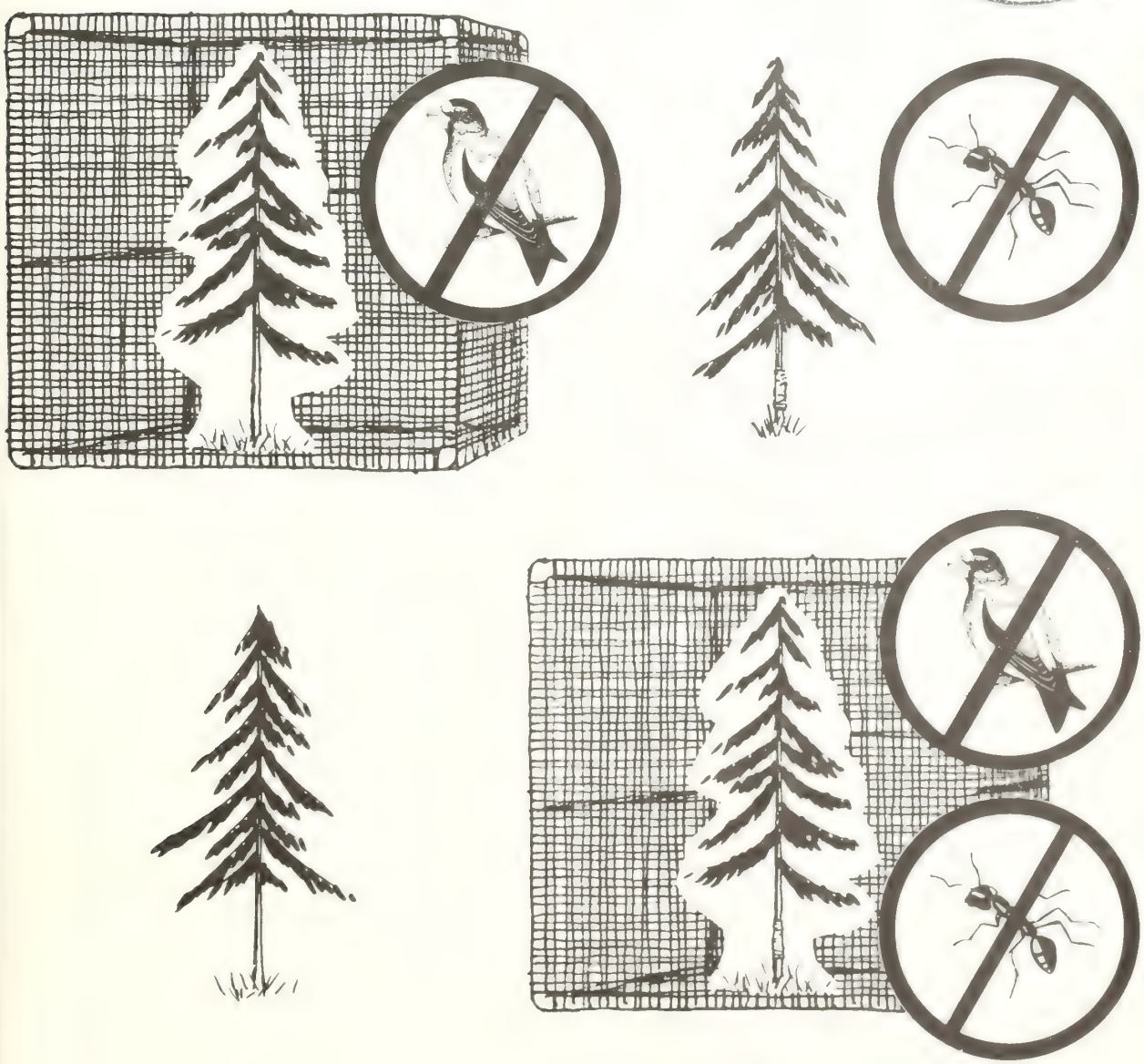

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Abstract

Campbell, Robert W.; Carlson, Clinton E.; Theroux, Leon J.; Egan, Thomas H. Some effects of predaceous birds and ants on the western spruce budworm. Res. Pap. PNW-315. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 5 p.

Effects of predaceous birds and ants on the western spruce budworm, *Choristoneura occidentalis,* were studied on seedlings of western larch and Douglas-fir in western Montana. On western larch, both birds and ants reduced survival of larval budworm (instars IV-VI). On Douglas-fir, larval survival on one site was reduced by ants but not by birds. On a second site, neither birds nor ants had any effect on larval survival on Douglas-fir. Ants, but not birds, continued to have a major effect on the survival of budworm pupae.

KEYWORDS: Predator-prey relations, predators (insect) -forest pest control, western spruce budworm, *Choristoneura occidentalis*.

Introduction

Birds and ants were major predators of the western spruce budworm, *Choristoneura occidentalis* Freeman, among populations studied in Washington and Idaho on about 9-m-tall Rocky Mountain Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and grand fir, *Abies grandis* (Dougl. ex D. Don) Lindl. (Campbell and others in press.) In western Montana, predaceous birds continued to be effective in destroying budworm pupae on branches approximately 20 m above the ground. Ants, however, had no discernible effect on the pupae on these higher branches (Campbell and Torgersen 1983). From these results, we concluded that birds were the dominant budworm predators in the upper crowns of taller host trees. Current studies in western Montana suggest that budworm larvae and pupae exhibit an exceptionally low survival rate on trees less than 2 m tall; and we speculated that ants, rather than birds, might be the dominant budworm predators on these seedlings. The principal purpose of this study was to test that hypothesis.

For budworm cohorts on small, $\leq$ 1-m-tall seedlings of two species (Douglas-fir and western larch, *Larix occidentalis* Nutt.), our objectives are to describe the effects of excluding birds, ants, and both groups on subsequent budworm density; and to evaluate the effects of birds, ants, and both groups on the survival rate of budworm pupae.

Method

The study was conducted in 1982 in the vicinity of Chamberlain and Pearson Creeks, about 90 km (56 mi) northeast of Missoula, Mont. Both sites are at about the 1 025-m (3,420 ft) elevation above mean sea level. The Pearson Creek site is about 8 km (5 mi) east of Chamberlain Creek. Both sites were logged in 1961 as seed tree regeneration cuts, and both were reasonably well stocked with western larch and Douglas-fir regeneration (about 1,750 trees per ha (700 trees per acre): 66 percent western larch and 34 percent Douglas-fir). Both sites were ecologically and physically similar on north-facing 20- to 40-percent slopes within the *Abies lasiocarpa/Xerophyllum tenax* habitat type (Pfister and others 1977).

At each site, 40 Douglas-fir seedlings and 40 western larch seedlings about 1 m (39 in) tall were selected for study. Within each species, the boles of half the seedlings were banded with a sticky barrier below the base of the live crown. Above these barriers, foliage was pruned to eliminate any possible bridges that ants might use to travel to and from these seedlings. Birds were excluded from half of the banded trees and half of the unbanded ones by 3/4-m^3 (about 20-ft^3) cages made from 1/2-in IPS polyvinyl pipe and 1- x 2-cm (about 0.5- x 1-in) polypropylene screen (fig. 1) (Campbell and others 1981). On each site and host species, all treatments (ants excluded, birds excluded, both groups excluded, and controls) were completely randomized. The treatments were applied when the bulk of the budworm population was entering instar IV.

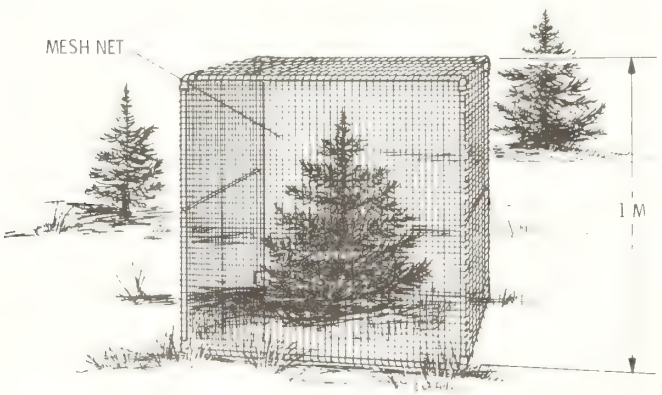

Figure 1.—Bird exclusion treatment.

Although the cage mesh did not appear to present a barrier to potential airborne insect enemies of the budworm, the cages may have interfered with some invertebrates. The sticky barriers would also prevent any crawling invertebrates on the ground from reaching the crowns of the treated seedlings. Significantly, however, ants are the only invertebrate group we have observed preying on the budworm in the Pacific Northwest (Campbell and others in press).

After pupation commenced, budworm pupae were collected from nearby populations by clipping twigs containing individual pupae. Two twigs were wired to branch tips on each seedling. For each site and host species, 20 pupae were installed on the 10 seedlings in each treatment category. A subsequent observation on the fate of these planted pupae provided a basis for estimating pupal survival from predation. Estimates produced by this method have been statistically indistinguishable from the much more labor-intensive effort needed to establish this rate among naturally occurring insects (Campbell and others 1982).

Two weeks after placement of the pupae-bearing twigs, we determined the status of these pupae. At the same time we also counted all naturally occurring budworms (larvae, pupae, and pupal exuviae) on each seedling.

All reported differences are based on Chi-square comparisons. To provide a more conservative test, we calculated Chi-square with Yates' correction (Dixon and Massey 1969).

Results and Discussion

Naturally Occurring Budworm

The total of all budworms (larvae, pupae, and pupal exuviae) found on seedlings in each treatment category (birds, ants, or both groups excluded, and controls) is shown for each site and host species in table 1. At the time of this final seedling examination, 36 percent of the 511 naturally occurring budworm were pupal exuviae and 12 percent were larvae. The remaining 52 percent were pupae. We infer from these percentages that most of the naturally occurring insects had pupated within just a few days of this final examination. Thus, differences in budworm densities among treatments were determined principally between instar IV and pupation.

On western larch at both sites, all other treatments contained significantly fewer budworms than were found on seedlings where both birds and ants had been excluded ($p < .05$). Thus, on this species both birds alone and ants alone had independent effects on budworm density.

On Douglas-fir in Chamberlain Creek, seedlings where birds had been excluded contained fewer budworms than those where both groups had been excluded ($p < .001$). Densities did not differ, however, between seedlings where ants had been excluded and those where both groups had been excluded. At this site ants therefore had a major effect on budworm density on Douglas-fir seedlings, whereas birds had no effect.

Neither birds nor ants had any effect on budworm density on Douglas-fir seedlings at Pearson Creek.

Table 1—Western spruce budworms found on control seedlings and on seedlings after birds, ants, or both groups had been excluded

Place	Host species	Treatment	Insects found[1]
Chamberlain Creek	western larch	Control	18 a
Chamberlain Creek	western larch	Ax[2]	42 b
Chamberlain Creek	western larch	Bx[3]	30 ab
Chamberlain Creek	western larch	ABx[4]	77 c
Chamberlain Creek	Douglas-fir	Control	24 a
Chamberlain Creek	Douglas-fir	Ax	94 b
Chamberlain Creek	Douglas-fir	Bx	20 a
Chamberlain Creek	Douglas-fir	ABx	81 b
Pearson Creek	western larch	Control	11 a
Pearson Creek	western larch	Ax	16 a
Pearson Creek	western larch	Bx	15 a
Pearson Creek	western larch	ABx	38 b
Pearson Creek	Douglas-fir	Control	6 a
Pearson Creek	Douglas-fir	Ax	13 a
Pearson Creek	Douglas-fir	Bx	13 a
Pearson Creek	Douglas-fir	ABx	13 a

[1] Insect densities in the same place and on the same species that are followed by the same letter are not significantly different.
[2] Ax = ants excluded.
[3] Bx = birds excluded
[4] ABx = both groups excluded.

Budworm Pupae

The fate of pupae placed on seedlings in each treatment category is shown for each site and host species in table 2.

At both sites and on both host species, missing pupae on control seedlings called "Control" did not differ from those where birds had been excluded (Bx). Thus, birds had no effect on the disappearance rate of these pupae. For further analysis, results have been pooled for insects found in these two categories (control + Bx) on each site and host species. Similarly, at both sites and on both host species, missing pupae on seedlings where ants had been excluded (Ax) did not differ from those where both groups had been excluded (ABx). Again, for further analysis, results from the two categories have been pooled (Ax + ABx).

At both sites and on both host species, more pupae were missing on seedlings that had been exposed to ants (control + Bx) than on those protected from ants (Ax + ABx) ($p < .05$ on Douglas-fir in Chamberlain Creek; $p < .01$ elsewhere). At both sites, ants had a major effect on the disappearance rate of pupae. In Chamberlain Creek, 49 percent of the pupae disappeared from unprotected seedlings versus 19 percent from protected ones. In Pearson Creek, the comparable figures are 65 percent disappearance from unprotected seedlings versus 21 percent on protected ones.

Table 2—Fate of pupae placed on control seedlings and on seedlings protected from birds, ants, and both groups

Place	Host species	Treatment	Total pupae	Missing	Other
Chamberlain Creek	western larch	Control	23	9	14
Chamberlain Creek	western larch	Ax	18	3	15
Chamberlain Creek	western larch	Bx	22	13	9
Chamberlain Creek	western larch	ABx	18	2	16
Chamberlain Creek	western larch	[Control + Bx]	45	22	23
Chamberlain Creek	western larch	[Ax + ABx]	36	5	31
Chamberlain Creek	Douglas-fir	Control	20	11	9
Chamberlain Creek	Douglas-fir	Ax	22	8	14
Chamberlain Creek	Douglas-fir	Bx	20	9	11
Chamberlain Creek	Douglas-fir	ABx	20	2	18
Chamberlain Creek	Douglas-fir	[Control + Bx]	40	20	20
Chamberlain Creek	Douglas-fir	[Ax + ABx]	42	10	32
Pearson Creek	western larch	Control	21	14	7
Pearson Creek	western larch	Ax	20	5	15
Pearson Creek	western larch	Bx	20	14	6
Pearson Creek	western larch	ABx	20	3	17
Pearson Creek	western larch	[Control + Bx]	41	28	13
Pearson Creek	western larch	[Ax + ABx]	40	8	32
Pearson Creek	Douglas-fir	Control	20	12	8
Pearson Creek	Douglas-fir	Ax	21	5	16
Pearson Creek	Douglas-fir	Bx	20	13	7
Pearson Creek	Douglas-fir	ABx	20	4	16
Pearson Creek	Douglas-fir	[Control + Bx]	40	25	15
Pearson Creek	Douglas-fir	[Ax + ABx]	41	9	32

Implication

Both birds and ants had an effect on the budworms on conifer seedlings. In particular, birds appear to have removed some of the late instars and, possibly, some of the pupae from seedlings of western larch. Ants appear to have removed some of the larvae from seedlings of both western larch and Douglas-fir. Ants continued to have a major effect on the survival of planted budworm pupae; birds had no effect on these pupae.

These results leave little doubt that ants were far more important than birds as predators of the western spruce budworm on the conifer seedlings in Montana. Stands at both Pearson Creek and Chamberlain Creek were regenerated through seed tree cuts—silvicultural systems appropriate for those sites. If the density of ants increased following the harvest, subsequent increased predation by the ants may give developing conifer seedlings some additional protection from the western spruce budworm.

Acknowledgments

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Campbell, Robert W.; Carlson, Clinton E.; Theroux, Leon J.; Egan, Thomas H. Some effects of predaceous birds and ants on the western spruce budworm. Res. Pap. PNW-315. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 5 p.

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KEYWORDS: Predator-prey relations, predators (insect) (-forest pest control, western spruce budworm, *Choristoneura occidentalis*.

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Characteristics of Residues in a Cable-Logged Area of Old-Growth Douglas-Fir

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Abstract

Pong, W. Y.; Henley, John W. Characteristics of residues in a cable-logged area of old-growth Douglas-fir. Res. Pap. PNW-316. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 30 p.

The volume and character of woody material on the ground in four old-growth Douglas-fir cutting units in the Cascade Range in Oregon were determined before and after harvesting by cable and yarding of unutilized material (YUM). Total volume of residue increased after logging in all units. Coarse residues were reduced by YUM yarding. Small changes in the defect condition of the timber can drastically affect the amount and character of the residues remaining on the site. Modifying bucking procedures can result in the removal of a considerable volume of usable residue.

Keywords: Residue management, residue treatment, logging effects, cable logging, old-growth stands, Douglas-fir, *Pseudotsuga menziesii,* Oregon (Cascade Range), Cascade Range—Oregon.

Research Summary

The volume and character of woody material on the ground in four study units of old-growth Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in Oregon were determined before and after harvesting by cable and yarding of unutilized material (YUM). Two silvicultural treatments (clearcut and partial cut) and two levels of YUM yarding were applied. Total volume of residue increased after logging in all study units but increased most in the clearcuts. Not all diameter classes of residue increased in volume after logging. As a group, the coarser, larger diameter residue decreased in volume after the harvesting operation. Yarding unutilized material appears to reduce the amount of large residue. Results, however, were not always consistent; some larger diameter classes of residue increased on each unit. Results further suggest that yarding unutilized material from small units with highly defective timber is less effective than from larger units containing timber that is nearly as defective or from larger units with timber that is much less defective.

The merchantable volume of logs removed from each unit was generally greater than the total volume of residue remaining on the unit and greater than the total unused volume of wood generated during the logging operation. In only one small unit with highly defective timber was the gross merchantable log volume removed less than either the gross volume of residue left on the ground or the total unused volume of wood generated. Results suggest that the amount and character of the residue remaining on a site depend heavily on the defective condition of the timber and can change drastically with small changes in amounts of defect.

From 34 to 56 percent of the residue remaining on units after harvesting had some potential for utilization. This was proportionately less than the volume of prelogging residue considered usable (38 to 71 percent of total residue per acre) because of the disproportionate large increase in the volume of unusable residue. The potential for utilization of residues (both natural and logging) was reduced as the direct result of harvesting activities and YUM yarding. A noticeable increase in the volume of slabs was recorded on all units. Most YUM either met or exceeded the minimum specifications for utilization. When combined with the gross volume of usable residue left on the ground, 35 to 65 percent of all residue was considered potentially usable.

The number of pieces of usable residue per acre (excluding YUM) increased in all units after harvesting, varying from three to nine times greater than the number before. Most of the increase was in shorter pieces in the smaller diameter classes.

Study results suggest that a considerable volume of the usable residue could have been removed by modifying the bucking procedures. Over 35 percent of the usable residue had been bucked from longer pieces. If left intact with the merchantable log or the YUM material, these pieces of residue could have been easily removed during the yarding operation.

Conversion Factors

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 acre = 0.404 686 2 hectare
1 cubic foot/acre = 0.069 972 5 cubic meter/hectare

1 pound (lb) = 0.453 6 kilogram
1 ton = 2,000 lb = 907.2 kilograms
1 bone-dry unit (BDU) of chips = 2,400 pounds

Species density (ovendry weight per green volume)
(Hartman, n.d., table E-1):
Coast Douglas-fir = 28.0 pounds per cubic foot
Western hemlock = 26.2 pounds per cubic foot

1 cubic-foot Douglas-fir = 0.011 666 6 BDU chips
1 cubic-foot western hemlock = 0.010 916 6 BDU chips

Higher heating values dry wood (Hartman, n.d., table G-1):
1 cubic-foot Douglas-fir = 249,000 British thermal units (Btu) per cubic foot
1 cubic-foot western hemlock = 204,000 Btu per cubic foot

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Introduction

Land managers attempting to achieve the goals and objectives of multiple-use forestry need information on logging residue to plan optimum utilization of the resource, minimize risk of fire, and prepare for reforestation.

Information on residue was obtained from three timber sale areas in the Pansy Creek drainage on the Estacada Ranger District of the Mount Hood National Forest. Three aerial logging systems—balloon, helicopter, and skyline (cable)—were used to log these areas. The aim of these studies was to evaluate the performance of each system in attaining land management objectives. Residue left after logging is an important factor in this evaluation.

This report provides information on the amount and character of residues left in four units of the area logged by cable. The information is site specific and unique to specific logging conditions but can be used in evaluating the utilization potential of residues, fuel loadings, and the effects of changes in market conditions and contract requirements in timber sales, such as yarding of unutilized material (YUM).[1] The character and volume of residues left in the balloon-logged area and in the helicopter-logged area were reported by Pong and Henley (1976, 1978).

Procedures

Terrain of the study area was steep and broken with slopes varying from 10 to 100 percent. Principal species in the area were old-growth coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Secondary species were western redcedar (*Thuja plicata* Donn ex D. Don), western white pine (*Pinus monticola* Dougl. ex D. Don), and true firs (*Abies* spp.).

Cruise volumes, logging specifications, and size of the four units are given in table 1.

1/ YUM is used for the yarding process (YUM yarding) and for the unutilized material that is yarded (YUM).

Table 1—Cruise data and logging specifications for 4 study units before cable logging, Pansy Creek drainage, Mount Hood National Forest

Study unit	Size	Cruise volume, Scribner rule: Gross	Net per acre	Defect	Cutting method	specifications
	Acres	Thousand board feet		Percent		
1	[illegible]	467	62	44.5	Clearcut	12-inch diameter inside bark or larger on large end, 10 feet long or longer
2	41	1,433	861	35	21	39.9	[illegible][2]	
3	59	4,136	3,677	70	62	[illegible]	[illegible]	
4	138	8,146	7,104	61	51	15.6	Partial cut[3]	8-inch diameter inside bark or larger on large end, 10 feet long or longer

1/ Yarding of unutilized material.

2/ About 50 percent of merchantable volume removed.

3/ About 65 percent of merchantable volume removed.

Logging specifications in the timber sale contract required that all logs that scaled one-third sound with a minimum net scale of 80 board feet be removed. These specifications applied to logs that were 6 inches and larger in diameter inside bark (d.i.b.) at the small end and at least 8 feet long. The contract also required yarding of unutilized materials according to specifications shown in table 1.

A planar intersect technique was used to inventory the downed woody residues. Woody pieces that intersect imaginary vertical sampling planes (each 200 feet long) dropped through the downed debris were tallied (Brown 1974, Van Wagner 1968). A systematic grid point sampling design, with random orientation of a sampling plane at each point, was used to inventory each unit (Howard and Ward 1972). At least 40 sample points were located in each unit. Pieces less than 3 inches in diameter were tallied as follows:

Diameter class (Inches)	Sampling plane (Feet)
0.25 to 0.99	6
1.0 to 2.99	10

Pieces 3 inches and larger were recorded by diameter to the nearest inch. A 200-foot sampling plane was used for these larger pieces.

Pieces qualifying for tally were downed woody material (twigs, stems, branches, and bolewood) from trees and shrubs. Slabs from shattered trees were recorded, as were twigs and branches deposited in and above the litter layer. But dead branches attached to boles of standing trees were not tallied, nor were cones, bark flakes, needles, leaves, grass, and forbs.

The size classes were chosen because they permit precise estimates of volume and they correspond to the standard moisture timelags used in the National Fire-Danger Rating System (Deeming and others 1972).

As each piece of residue 3 inches d.i.b. and larger was inventoried, the piece was classified according to its potential for utilization. Pieces less than 4 feet long were not considered usable and were classed as fuel. Pieces so decayed or splintered that they would not hold together if yarded were also classed as fuel. All others were placed in one of the following categories:

1. From a felled tree and bucked on at least one end.

2. From a felled tree and broken on both ends.

3. From prelogging (natural) residue (for example, dead and down windthrows) and bucked on at least one end.

4. From prelogging residue and broken on both ends.

Information on species, length, and soundness was obtained for each piece considered usable. Length was recorded to the nearest foot. Soundness or percentage of firmwood (proportion of wood usable for pulp chips) was estimated to the nearest 10 percent at the point of intersection with the sampling plane. Estimates of soundness were based on the proportion of the cross-sectional area that was sound and was judged usable for pulp chips. Decayed or excessively splintered material was considered unusable and was classed as fuel. The cross-sectional area at the sampling point was usually not visible, and soundness was estimated on the basis of surface and end characteristics of the piece and by a limited amount of sounding and chopping with hatchets.

These sampling procedures were used to inventory the natural residues on the unit before any harvesting activities and also the residues left after the yarding operations were completed. The logging residues were sampled after the required yarding of unutilized material was complete, but before any further treatment of the remaining slash.

esults

otal Residue Volume ncreased After arvesting

The gross volume of all residues on the ground increased in all four study units after the harvesting operation (table 2). The largest increases were in the clearcut units (1 and 3), where residue volumes increased 83 and 54 percent, respectively. A smaller increase was recorded in the partial cut units; 33 percent in unit 2 and 28 percent in unit 4. The volumes of residue before and after logging are presented in table 3 by diameter class. The proportion of total residue in each size class on each unit, before and after logging, is shown in figure 1.

Table 2—Average gross volume of usable and unusable residue, pieces of usable residue before and after cable logging, and gross volume of YUM [1/] and merchantable logs removed from 4 study units, Pansy Creek drainage, Mount Hood National Forest

Study unit and cutting method	Volume of residue			Pieces of usable residue	YUM	YUM plus usable residue	Volume of merchantable logs removed
	Usable	Unusable	Total				
	- -Cubic feet per acre- -			Number per acre	- - -Cubic feet per acre- - -		
Unit 1 (clearcut):							
Before logging	911	1,457	2,368	53	--	911	--
After logging	1,472	2,858	4,330	486	58	1,530	3,486
Unit 2 (partial cut):							
Before logging	1,737	693	2,430	133	--	1,737	--
After logging	1,528	1,698	3,226	436	553	2,081	5,265
Unit 3 (clearcut):							
Before logging	1,745	732	2,477	146	--	1,745	--
After logging	2,141	1,666	3,807	695	983	3,124	8,274
Unit 4 (partial cut):							
Before logging	1,552	1,113	2,665	110	--	1,552	--
After logging	1,814	1,595	3,409	725	692	2,506	9,732

1/ Yarding of unutilized material (removed during logging operation).

Table 3—Average gross volume of residue on 4 study units before and after cable logging, by diameter class, Pansy Creek drainage, Mount Hood National Forest

Diameter class	Unit 1		Unit 2		Unit 3		Unit 4	
	Before logging[1/]	After logging[2/]	Before logging[1/]	After logging[2/]	Before logging[1/]	After logging[2/]	Before logging[1/]	After logging[2/]
Inches	Cubic feet per acre							
0.26- 1.0	79.0	449.6	82.4	199.9	105.3	350.5	121.5	202.4
1.1 - 2.9	134.3	539.8	123.8	366.0	210.7	794.8	160.2	571.4
3.0 - 4.4	63.4	185.1	63.1	120.6	53.2	119.6	62.5	193.0
4.5 - 7.4	91.2	339.4	127.3	419.8	130.5	303.8	100.1	341.6
7.5 -10.4	253.8	288.9	224.9	341.5	217.9	623.0	298.7	419.5
10.5 -13.4	432.3	332.5	218.8	265.2	220.2	426.1	404.9	278.0
13.5 -16.4	651.4	297.7	288.1	276.0	311.9	346.4	257.8	307.3
16.5 -19.4	90.7	275.8	149.5	90.8	144.6	106.0	327.5	272.6
19.5 -22.4	306.4	224.7	195.4	175.8	277.8	342.7	270.9	162.9
22.5 -25.4	0	217.2	107.5	163.5	439.2	160.2	203.4	109.9
25.5 -28.4	73.1	128.6	157.7	0	97.1	0	87.2	68.1
28.5 -31.4	126.0	42.0	377.9	42.0	84.0	0	279.9	78.5
31.5 -34.4	0	50.8	0	104.7	101.7	0	0	107.9
34.5+	60.5	0	306.4	178.1	82.3	0	50.4	0
Slabs	5.7	957.8	7.6	482.4	1.1	234.5	40.0	296.0
Total[3/]	2,367.9	4,329.9	2,430.3	3,226.3	2,477.4	3,807.4	2,664.9	3,409.0

1/ Dead and down material, which includes material not yardable, less than 10 percent sound, and less than 3 inches in diameter and 4 feet long.

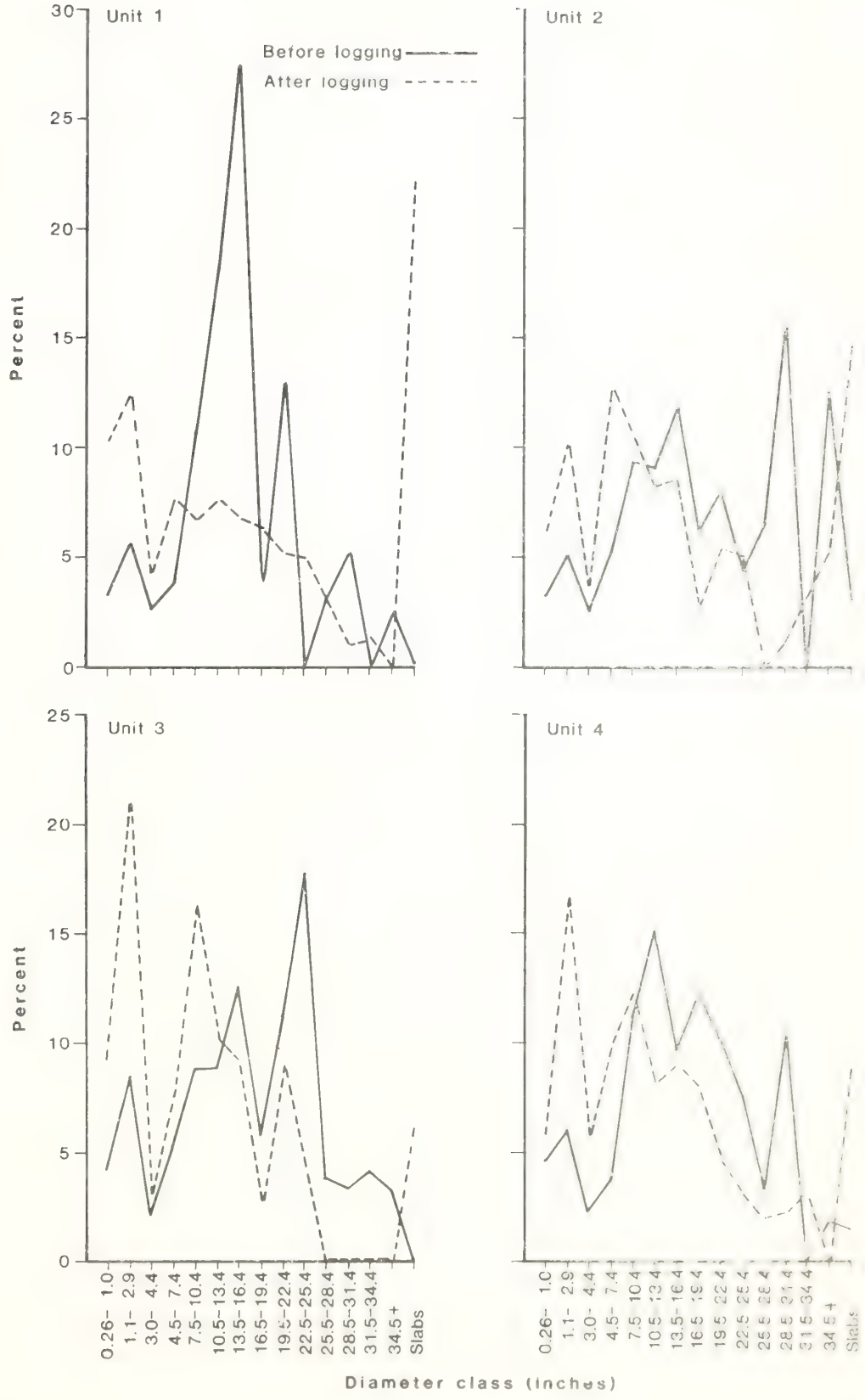
2/ All down material, which includes material not yardable, less than 10 percent sound, and less than 3 inches in diameter and 4 feet long.

3/ Totals may be off because of rounding.

Coarse Residues Reduced by YUM Yarding

Not all diameter classes of residue increased in volume after logging; as a group, the large diameter residues decreased (table 3). The larger material also represented proportionately less of the total volume of residue remaining on each unit (fig. 1). This seems to suggest that YUM yarding had some impact in reducing the amount of large residue. Yarding unutilized material, however, did not give consistent results for all diameter classes of residue in all study units. Some classes increased in volume in each unit in spite of YUM yarding. Unit 1, in particular, registered increases in residue for several of the larger diameter classes (table 3). The low gross volume of YUM material removed from unit 1 (58 cubic feet per acre, table 2) indicates a buildup of larger residue. The volume of YUM removed from unit 2 was 553 cubic feet per acre; from unit 3, 983 cubic feet; and unit 4, 692 cubic feet. These results suggest that yarding unutilized material from a small unit with timber containing a large amount of defect (9 acres, 44.5 percent defect) is less effective than from a larger unit with almost as much defect in the timber (unit 2) and from larger units that have much less defective timber (units 3 and 4) (table 1). These results further suggest that much of the buildup of larger residue on unit 1 may have been in pieces not meeting the length requirement for YUM, and they were therefore left on the site.

The fact that the volume of large residue decreased for many diameter classes in all units after logging indicates that some of the prelogging residue had been removed during the logging operation. Removing this material as YUM probably accounted for much of this reduction; however, some reduction may also have resulted from the utilization of the sounder pieces of prelogging residue, especially the larger diameter material.



gure 1.—Percent of total gross olume of residues in each ameter class and in slabs before nd after cable logging on four udy units, Pansy Creek drain- ge, Mount Hood National Forest.

The gross volume of merchantable logs removed from each unit during the cable logging operation, as tallied at the truck scale station, is presented in table 2. Except for unit 1, the merchantable volume of logs removed from each unit was greater than the total residue volume remaining on the unit and greater than the total unused wood volume (total logging residue plus YUM) generated during the logging operation. In unit 1, however, gross volume of merchantable logs removed was 3,486 cubic feet per acre. This was less than either the total gross volume of residue left on the ground (4,330 cubic feet per acre) or the total unused wood volume of 4,388 cubic feet per acre. The defective condition of the timber on unit 1 probably accounts for a major part of the low volume of merchantable logs.

Utilization Potential of Residues

Residue with some potential for utilization is defined as material that can be yarded without breaking up and is at least 10 percent sound, 3 inches and larger in diameter, and at least 4 feet long. The volume of prelogging residues meeting these specifications on each unit was:

Unit	Volume		Coefficient of variation
	(Cubic feet per acre)	(Percent of total)	(Percent)
1	911	38	89.7
2	1,737	71	112.4
3	1,745	70	99.8
4	1,552	58	97.8

These residues were not uniformly distributed on the units but were in scattered, sparse concentrations. This is evident from the high coefficients of variation recorded for the units.

The volume of prelogging residues by diameter and length classes for each unit is presented in tables 4-7. The larger and sounder natural residues were probably salvaged during the harvesting operation; some may have been removed as YUM and others left on the site. The decrease of usable residue after logging on unit 2 (table 2) strongly suggests that prelogging residue was removed from the units as salvage and/or YUM. Volumes of usable and unusable prelogging residues for each unit are shown in figure 2 and summarized in table 2.

Table 4—Average gross and net volumes of usable residue on study unit 1 before cable logging, by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest [1/]

Diameter class	Length class (feet)									
	4.0-7.9		8.0-13.9		14.0-20.9		21.0+		All classes	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
Inches	- - - - - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - - - - -									
3.0- 4.4	1.6	1.6	0	0	1.5	1.3	1.6	1.5	4.7	4.4
4.5- 7.4	1.7	1.0	6.7	5.0	3.4	2.4	9.7	9.2	21.5	17.6
7.5-10.4	6.0	3.6	7.7	5.8	13.6	7.7	49.7	46.4	76.9	63.4
10.5-13.4	6.7	4.0	20.2	20.2	33.6	26.2	26.9	22.8	87.3	73.2
13.5-16.4	0		35.8	27.5	60.5	55.9	102.6	71.9	198.9	155.3
16.5-19.4	0		15.1	12.1	15.1	12.1	0		30.2	24.2
19.5-22.4	18.7	18.7	18.7	18.7	18.7	18.7	175.8	125.3	231.8	181.3
22.5-25.4									0	
25.5-28.4	0		0		0		73.1	69.5	73.1	69.5
28.5-31.4	0		42.0	42.0	0		84.0	84.0	126.0	126.0
31.5-34.4									0	
34.5+	0		0		0		60.5	60.5	60.5	60.5
Slabs									0	
Total [2/]	34.6	28.9	146.1	131.2	146.3	124.1	583.8	491.1	910.8	775.2

1/ Includes all dead and down material averaging at least 3 inches in diameter (inside bark) and 4 feet long, at least 10 percent sound, and yardable.

2/ Totals may be off because of rounding.

Table 5—Average gross and net volumes of usable residue on study unit 2 before cable logging, by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Diameter class	Length class (feet) 4.0-7.9 Gross	4.0-7.9 Net	8.0-13.9 Gross	8.0-13.9 Net	14.0-20.9 Gross	14.0-20.9 Net	21.0+ Gross	21.0+ Net	All classes Gross	All classes Net
Inches	-Cubic feet per acre-									
3.0- 4.4	5.2	1.4	9.5	4.7	6.4	3.1	2.7	0.9	23.7	10.2
4.5- 7.4	12.0	4.7	23.5	8.8	18.9	8.1	34.1	19.1	88.5	40.8
7.5-10.4	10.6	1.1	37.7	14.8	63.6	36.6	70.4	35.6	182.4	88.1
10.5-13.4	11.3	2.3	6.7	0	46.0	9.3	101.0	46.7	165.1	58.2
13.5-16.4	9.1	.9	54.1	10.2	61.7	5.6	78.7	46.4	203.7	63.2
16.5-19.4	0		0		30.2	10.6	68.8	22.7	89.1	33.3
19.5-22.4	0		45.2	9.0	22.6	2.3	127.6	43.9	195.4	55.2
22.5-25.4	0		0		26.9	26.9	80.6	26.9	107.5	53.7
25.5-28.4	31.5	31.5	0		0		126.1	44.1	157.7	75.7
28.5-31.4	0		42.0	8.4	0		167.9	67.2	209.9	75.6
31.5-34.4									0	
34.5+	82.3	24.7	0		0		224.1	119.1	306.4	143.8
Slabs	0		3.8	1.7	3.8	.8	0		7.6	2.4
Total 2/	162.1	66.6	222.4	57.7	280.1	103.2	1,072.3	472.6	1,736.9	700.1

1/ Includes all dead and down material averaging at least 3 inches in diameter (inside bark) and 4 feet long, at least 10 percent sound, and yardable.

2/ Totals may be off because of rounding.

Table 6—Average gross and net volumes of usable residue on study unit 3 before cable logging, by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Diameter class	Length class (feet) 4.0-7.9 Gross	4.0-7.9 Net	8.0-13.9 Gross	8.0-13.9 Net	14.0-20.9 Gross	14.0-20.9 Net	21.0+ Gross	21.0+ Net	All classes Gross	All classes Net
Inches	-Cubic feet per acre-									
3.0- 4.4	12.3	6.1	6.5	4.6	7.6	5.0	2.2	0.9	28.6	16.5
4.5- 7.4	10.9	3.8	20.5	8.6	18.8	8.1	46.1	25.1	96.4	45.6
7.5-10.4	4.7	3.7	14.6	8.0	35.6	9.7	94.0	49.6	148.7	71.1
10.5-13.4	6.7	1.3	20.2	8.1	58.4	31.5	134.9	75.2	220.2	116.0
13.5-16.4	0		63.3	16.6	30.2	18.4	218.4	128.5	311.9	163.5
16.5-19.4	15.1	0	0		15.1	0	114.4	81.9	144.6	81.9
19.5-22.4	0		18.7	1.9	0		78.6	22.9	97.2	24.7
22.5-25.4	26.9	26.9	0		136.7	39.0	168.1	118.1	331.7	184.0
25.5-28.4	0		0		31.5	15.8	65.5	49.0	97.1	64.8
28.5-31.4	0		0		0		84.0	4.2	84.0	4.2
31.5-34.4	0		0		0		101.7	96.3	101.7	96.3
34.51+	0		0		0		82.3	8.2	82.3	8.2
Slabs	0		1.1	.1	0		0		1.1	.1
Total 2/	76.6	41.8	144.5	47.8	334.0	127.5	1,190.2	660.0	1,745.3	877.1

1/ Includes all dead and down material averaging at least 3 inches in diameter (inside bark) and 4 feet long, at least 10 percent sound, and yardable.

2/ Totals may be off because of rounding.

Table 7—Average gross and net volumes of usable residue on study unit 4 before cable logging, by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Diameter class	Length class (feet) 4.0-7.9 Gross	4.0-7.9 Net	8.0-13.9 Gross	8.0-13.9 Net	14.0-20.9 Gross	14.0-20.9 Net	21.0+ Gross	21.0+ Net	All classes Gross	All classes Net
Inches	- - -

Much of the prelogging residue was defective; average soundness varied from 40 percent on unit 2 to 85 percent on unit 1 (table 8). After logging, soundness of usable residues averaged higher on three of the units (77 percent for units 2 and 3, and 78 percent for unit 4) but lower on unit 1 (57 percent) (tables 9-12). The salvage of the larger and sounder prelogging residues during the logging operation probably contributed to the reduction of the average soundness of the remaining residues on unit 1. The exceptionally low volume of YUM removed from unit 1 compared with the other units (table 2) was also a factor. Generally, the yarding of unutilized material would increase the average soundness of the material left on the logging site through the removal of defective, nonmerchantable logs. The highly defective condition of the usable residue left on unit 1 (table 9) suggests that only the sounder, less defective, nonmerchantable logs were removed during the YUM operation. The species composition and soundness data of the usable residues on each unit before the harvesting operation are presented in table 8; after the operation, in tables 9-12.

With the exception of unit 2, volume of usable residue increased on each unit after harvesting; however, compared with the proportions of the prelogging residues considered usable, the usable portion of the logging residues represents a smaller percentage of the total residue generated on each unit because of the disproportionately large increase in volume of unusable logging residues (table 2).

According to study specifications, the amount of residue remaining on each unit after logging that could have been used was:

Unit	Volume		Coefficient of variation
	(Cubic feet per acre)	(Percent of total)	(Percent)
1	1,472	34	70.0
2	1,528	47	65.9
3	2,141	56	62.8
4	1,814	53	73.8

The average gross and net volumes of usable logging residue remaining on each unit are shown by soundness and by diameter and length classes in tables 13-16. Volumes of usable and unusable residue by 10- and 50-percent soundness classes before and after logging are presented in figure 2, and a summary of volumes of each unit is given in table 2.

Table 8—Average gross and net volumes of usable residue on 4 study units before cable logging, by species, Pansy Creek drainage, Mount Hood National Forest 1/

Species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		Percent	
Study unit 1:				
Douglas-fir	567.5	465.8	82.1	62.3
Western hemlock	258.7	230.7	89.2	28.4
Western redcedar	0			
Pines	59.9	56.2	93.9	6.6
Other softwoods	24.7	22.4	90.9	2.7
Hardwoods	0			
Total or average 2/	910.8	775.2	85.1	100.0
Study unit 2:				
Douglas-fir	547.4	199.6	36.5	31.5
Western hemlock	1,072.8	444.5	41.4	61.8
Western redcedar	97.2	50.0	51.5	5.6
Pines	4.9	.8	16.5	.3
Other softwoods	13.4	4.6	34.1	.8
Hardwoods	1.2	.6	50.0	.1
Total or average 2/	1,736.9	700.1	40.3	100.0
Study unit 3:				
Douglas-fir	1,174.0	563.8	48.0	67.3
Western hemlock	363.4	187.6	51.6	20.8
Western redcedar	130.9	102.3	78.1	7.5
Pines	0			
Other softwoods	77.0	23.5	30.5	4.4
Hardwoods	0			
Total or average 2/	1,745.3	877.1	50.3	100.0
Study unit 4:				
Douglas-fir	1,169.9	824.8	70.5	75.4
Western hemlock	309.2	231.8	75.0	19.9
Western redcedar	35.2	31.3	88.9	2.3
Pines	0			
Other softwoods	38.1	27.9	73.2	2.5
Hardwoods	0			
Total or average 2/	1,552.4	1,115.8	71.9	100.0

1/ Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

2/ Totals may be off because of rounding.

Table 9—Average gross and net volumes of usable residue on study unit 1 after cable logging, by soundness category and species, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		- - - -Percent- - - -	
75+ percent sound:				
Douglas-fir	93.1	85.6	92.0	14.8
Western hemlock	184.4	178.5	96.8	29.4
Western redcedar	25.3	23.5	92.8	4.0
Pines	0			
Other softwoods	324.2	322.2	99.4	51.7
Hardwoods	0			
Total or average[2/]	627.0	609.8	97.3	100.0
50+ percent sound:				
Douglas-fir	170.7	126.9	74.3	21.0
Western hemlock	269.2	225.0	83.6	33.1
Western redcedar	32.4	28.4	87.7	4.0
Pines	0	--	--	--
Other softwoods	340.7	331.3	97.2	41.9
Hardwoods	0	--	--	--
Total or average[2/]	813.0	711.6	87.5	100.0
30+ percent sound:				
Douglas-fir	244.5	154.9	63.4	23.1
Western hemlock	416.3	271.2	65.1	39.3
Western redcedar	32.4	28.4	87.7	3.1
Pines	0			
Other softwoods	365.0	339.1	92.9	34.5
Hardwoods	0			
Total or average[2/]	1,058.2	793.6	75.0	100.0
10+ percent sound:				
Douglas-fir	253.9	156.5	61.6	17.3
Western hemlock	773.7	309.8	40.0	52.6
Western redcedar	32.4	28.4	87.7	2.2
Pines	0			
Other softwoods	411.8	347.1	84.3	28.0
Hardwoods	0			
Total or average[2/]	1,471.8	841.8	57.2	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 10—Average gross and net volumes of usable logging residue on study unit 2 after cable logging, by soundness category and species, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		-Percent-	
75+ percent sound:				
Douglas-fir	261.0	252.7	96.8	26.4
Western hemlock	461.7	441.8	95.7	46.7
Western redcedar	99.3	89.0	89.6	10.0
Pines	4.7	3.7	80.0	.5
Other softwoods	64.6	64.0	99.1	6.5
Hardwoods	97.6	97.0	99.4	9.9
Total or average[2/]	986.8	948.2	95.9	100.0
50+ percent sound:				
Douglas-fir	379.8	321.4	84.6	30.9
Western hemlock	549.3	495.9	90.3	44.6
Western redcedar	126.2	106.0	84.0	10.3
Pines	4.7	3.7	80.0	.4
Other softwoods	72.1	68.3	94.6	5.9
Hardwoods	98.8	97.7	98.9	8.0
Total or average[2/]	1,230.8	1,092.9	88.6	100.0
30+ percent sound:				
Douglas-fir	446.3	343.3	76.9	31.6
Western hemlock	641.0	527.5	82.3	45.3
Western redcedar	129.6	107.3	82.8	9.2
Pines	4.7	3.7	80.0	.3
Other softwoods	92.5	76.2	82.4	6.5
Hardwoods	99.9	98.0	98.1	7.1
Total or average[2/]	1,413.9	1,156.1	81.8	100.0
10+ percent sound:				
Douglas-fir	485.5	349.9	72.1	31.8
Western hemlock	700.0	538.2	76.9	45.8
Western redcedar	129.6	107.3	82.8	8.5
Pines	4.7	3.7	80.0	.3
Other softwoods	100.3	77.8	77.5	6.6
Hardwoods	107.9	99.4	92.1	7.1
Total or average[2/]	1,528.0	1,176.4	77.0	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 11—Average gross and net volumes of usable logging residue on study unit 3 after cable logging, by soundness category and species, Pansy Creek drainage, Mount Hood National Forest 1/

Soundness category and species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		- - - -Percent- - - -	
75+ percent sound:				
Douglas-fir	644.7	634.2	98.4	42.6
Western hemlock	786.2	767.2	97.6	52.0
Western redcedar	45.3	42.6	94.0	3.0
Pines	0			
Other softwoods	34.3	34.3	100.0	2.3
Hardwoods	2.4	2.4	100.0	.2
Total or average 2/	1,512.9	1,480.8	97.9	100.0
50+ percent sound:				
Douglas-fir	742.8	684.7	92.2	44.3
Western hemlock	850.0	804.1	94.6	50.7
Western redcedar	46.2	43.0	93.1	2.8
Pines	0			
Other softwoods	34.3	34.3	100.0	2.0
Hardwoods	2.4	2.4	100.0	.1
Total or average 2/	1,675.7	1,568.5	93.6	100.0
30+ percent sound:				
Douglas-fir	752.4	687.5	91.4	43.0
Western hemlock	891.6	18.7	91.8	51.0
Western redcedar	68.1	50.2	73.6	3.9
Pines	0			
Other softwoods	34.3	34.3	100.0	2.0
Hardwoods	2.4	2.4	100.0	.1
Total or average 2/	1,748.9	1,593.1	91.1	100.0
10+ percent sound:				
Douglas-fir	874.4	699.7	80.0	40.8
Western hemlock	1,161.9	856.7	73.7	54.3
Western redcedar	68.1	50.2	73.6	3.2
Pines	0			
Other softwoods	34.3	34.3	100.0	1.6
Hardwoods	2.4	2.4	100.0	.1
Total or average 2/	2,141.1	1,643.4	76.8	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 12—Average gross and net volumes of usable logging residue on study unit 4 after cable logging, by soundness category and species, Pansy Creek drainage, Mount Hood National Forest 1/

Soundness category and species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		- - - -Percent- - - -	
75+ percent sound:				
Douglas-fir	520.8	508.0	97.6	42.3
Western hemlock	377.8	371.7	98.4	30.7
Western redcedar	85.6	83.2	97.2	7.0
Pines	3.0	3.0	100.0	.2
Other softwoods	242.0	228.5	94.4	19.7
Hardwoods	1.3	1.3	100.0	.1
Total or average 2/	1,230.3	1,195.6	997.2	100.0
50+ percent sound:				
Douglas-fir	607.1	555.1	91.4	42.6
Western hemlock	447.2	412.6	92.3	31.4
Western redcedar	85.6	83.2	97.2	6.0
Pines	3.0	3.0	100.0	.2
Other softwoods	279.5	251.3	89.9	19.6
Hardwoods	1.3	1.3	100.0	.1
Total or average 2/	1,423.5	1,306.4	91.8	100.0
30+ percent sound:				
Douglas-fir	691.7	587.8	85.0	41.6
Western hemlock	472.3	421.5	89.2	28.4
Western redcedar	89.4	84.3	94.3	5.4
Pines	3.0	3.0	100.0	.2
Other softwoods	404.0	296.9	73.5	24.3
Hardwoods	1.3	1.3	100.0	.1
Total or average 2/	1,661.6	1,394.7	83.9	100.0
10+ percent sound:				
Douglas-fir	736.8	595.9	80.9	40.6
Western hemlock	520.5	427.4	82.1	28.7
Western redcedar	89.4	84.3	94.3	4.9
Pines	3.0	3.0	100.0	.2
Other softwoods	462.6	304.9	65.9	25.5
Hardwoods	1.3	1.3	100.0	.1
Total or average 2/	1,813.5	1,416.7	78.1	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 13—Average gross and net volumes of usable residue on study unit 1 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and diameter class	Length class (feet)								All classes	
	4.0-7.9		8.0-13.9		14.0-20.9		21.0+			
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
Inches	- - -

Table 14—Average gross and net volumes of usable logging residue on study unit 2 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and diameter class	Length class (feet)									
	4.0-7.9		8.0-13.9		14.0-20.9		21.0+		All classes	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
Inches	- - - - - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - - - - -									
75+ percent sound:										
3.0- 4.4	27.3	26.7	25.3	24.9	24.0	23.8	17.4	17.4	[illegible]	[illegible]
4.5- 7.4	45.4	44.3	88.4	87.1	81.4	78.9	99.7	98.4	315.1	308.7
7.5-10.4	24.3	22.0	75.5	71.7	53.8	52.0	49.6	47.5	203.2	194.0
10.5-13.4	24.7	24.1	21.3	21.3	23.7	20.6	24.8	22.7	94.5	88.7
13.5-16.4	0		21.1	18.1	10.5	10.5	30.2	26.0	61.8	[illegible]
16.5-19.4	28.6	25.6	47.1	45.4	0		15.1	13.6	90.8	84.6
19.5-22.4	18.7	18.7	0		0		22.6	18.1	41.2	[illegible]
22.5-25.4	26.9	26.9	0		0		0	0	26.9	26.9
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+	57.1	57.1	0		0		0		57.1	57.1
Slabs	.7	.7	3.3	3.3	0		0		4.0	4.0
Total [2/]	253.7	246.0	282.1	271.8	193.4	186.7	259.6	243.7	988.8	948.2
50+ percent sound;										
3.0- 4.4	29.2	28.0	27.2	25.9	24.8	24.4	17.4	17.4	98.7	95.6
4.5- 7.4	57.3	51.4	95.8	91.3	87.7	82.5	110.6	104.5	351.4	329.7
7.5-10.4	34.0	27.4	95.1	83.9	66.0	60.9	59.4	53.1	254.5	225.3
10.5-13.4	24.7	24.1	39.3	33.3	37.1	30.0	30.5	26.1	131.6	113.4
13.5-16.4	18.3	11.0	30.2	24.5	22.4	17.7	39.4	32.4	110.3	85.5
16.5-19.4	28.6	25.6	47.1	45.4	0		15.1	13.6	90.8	84.6
19.5-22.4	18.7	18.7	0		37.3	20.5	22.6	18.1	78.6	57.2
22.5-25.4	26.9	26.9	26.9	13.4	0		0		53.7	40.3
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+	57.1	5.71	0		0		0		57.1	57.1
Slabs	.7	.7	3.3	3.3	0		0		4.0	4.0
Total [2/]	295.6	270.8	365.0	320.9	275.3	236.0	295.0	265.2	1,230.8	1,092.9
30+ percent sound:										
3.0- 4.4	30.5	28.4	28.4	26.3	26.3	24.8	17.4	17.4	102.6	96.9
4.5- 7.4	60.8	52.8	102.0	93.3	90.0	83.3	111.8	104.9	364.6	334.3
7.5-10.4	40.0	29.5	109.1	89.5	75.3	64.2	62.4	54.3	286.8	237.5
10.5-13.4	31.4	26.1	52.8	38.0	51.7	35.1	36.1	27.8	172.0	126.8
13.5-16.4	18.3	11.0	30.2	24.5	22.4	17.7	39.4	32.4	110.3	85.5
16.5-19.4	28.6	25.6	47.1	45.4	0		15.1	13.6	90.8	84.6
19.5-22.4	18.7	18.7	0	0	37.3	20.5	59.9	33.0	115.9	72.2
22.5-25.4	26.9	26.9	26.9	13.4	0		56.0	16.8	109.8	57.1
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4										
34.5+	57.1	57.1	0		0		0		57.1	57.1
Slabs	.7	.7	3.3	3.3	0		0		4.0	4.0
Total [2/]	313.0	276.7	399.8	333.6	303.0	245.6	398.1	300.2	1,413.9	1,155.1
10+ percent sound:										
3.0- 4.4	30.5	28.4	29.2	26.3	26.3	24.8	18.2	17.6	104.1	97.1
4.5- 7.4	64.7	53.6	103.2	93.5	92.3	83.5	111.8	104.9	372.0	335.6
7.5-10.4	47.6	31.1	112.1	90.1	75.3	64.2	62.4	54.3	297.4	[illegible]
10.5-13.4	31.4	26.1	52.8	38.0	78.7	40.5	36.1	27.8	199.0	132.2
13.5-16.4	18.3	11.0	40.7	27.4	31.6	18.6	60.5	34.5	151.1	91.5
16.5-19.4	28.6	25.6	47.1	45.4	[illegible]		15.1	13.6	90.8	[illegible]
19.5-22.4	18.7	18.7	[illegible]		37.3	20.5	59.9	33.0	[illegible]	72.2
22.5-25.4	26.9	26.9	26.9	13.4	26.9	5.4	56.0	16.8	136.6	62.5
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+	57.1	57.1	0		0		[illegible]		57.1	57.1
Slabs	.7	.7	3.3	3.3	0		[illegible]		4.0	4.0
Total [2/]	324.6	[illegible]	415.2	[illegible]	[illegible]	257.5	[illegible]	[illegible]	1,528.0	1,176.4

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 15—Average gross and net volumes of usable logging residue on study unit 3 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and diameter class	Length class (feet) 4.0-7.9 Gross	4.0-7.9 Net	8.0-13.9 Gross	8.0-13.9 Net	14.0-20.9 Gross	14.0-20.9 Net	21.0+ Gross	21.0+ Net	All classes Gross	All classes Net
Inches	- - - - - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - - - - -									
75+ percent sound:										
3.0- 4.4	46.0	45.5	30.8	30.6	20.3	20.1	7.9	7.8	104.9	104.0
4.5- 7.4	43.4	41.3	90.6	89.9	89.1	87.5	48.9	48.9	272.0	267.5
7.5-10.4	90.0	85.5	143.6	142.0	176.3	171.4	99.5	93.2	509.4	492.2
10.5-13.4	91.3	88.2	77.7	76.3	88.4	85.8	46.3	44.6	303.7	294.9
13.5-16.4	34.9	34.9	58.7	58.7	0		0		93.6	93.6
16.5-19.4	16.3	16.3	0		0		0		16.3	16.3
19.5-22.4	77.4	77.4	0		0		0		77.4	77.4
22.5-25.4									0	
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+									0	
Slabs	84.1	84.0	41.3	40.8	8.4	8.4	1.7	1.7	135.5	134.9
Total [2/]	483.4	473.1	442.7	438.2	382.5	373.2	204.3	196.2	1,512.9	1,480.8
50+ percent sound:										
3.0- 4.4	47.0	46.0	33.1	31.9	20.3	20.1	7.9	7.8	108.3	105.8
4.5- 7.4	46.1	42.7	96.9	93.3	93.3	90.1	48.9	48.9	285.2	275.0
7.5-10.4	90.0	85.5	149.3	144.8	179.9	173.3	99.5	93.2	518.7	496.8
10.5-13.4	91.3	88.2	94.0	86.0	88.4	85.8	46.3	44.6	320.0	304.6
13.5-16.4	49.4	45.0	58.7	58.7	0		11.1	5.5	119.1	109.3
16.5-19.4	16.3	16.3	0		0		18.3	9.2	34.7	25.5
19.5-22.4	77.4	77.4	0		27.4	13.7	27.4	13.7	132.1	104.7
22.5-25.4									0	
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+									0	
Slabs	101.7	93.6	45.9	43.1	8.4	8.4	1.7	1.7	157.7	146.9
Total [2/]	519.2	494.8	477.8	457.8	417.7	391.4	261.0	224.6	1,675.7	1,568.5
30+ percent sound:										
3.0- 4.4	48.1	46.3	34.0	32.2	21.2	20.5	7.9	7.8	111.1	106.7
4.5- 7.4	46.1	42.7	101.7	95.0	95.3	90.7	48.9	48.9	292.1	277.3
7.5-10.4	94.5	86.9	149.3	144.8	185.6	175.0	105.2	95.5	534.6	502.1
10.5-13.4	91.3	88.2	94.0	86.0	104.7	90.7	54.4	47.1	344.4	312.0
13.5-16.4	49.4	45.0	58.7	58.7	12.7	5.1	11.1	5.5	131.9	114.3
16.5-19.4	16.3	16.3	0		0		18.3	9.2	34.7	25.5
19.5-22.4	77.4	77.4	0		27.4	13.7	27.4	13.7	132.1	104.7
22.5-25.4									0	
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+									0	
Slabs	112.1	97.2	45.9	43.1	8.4	8.4	1.7	1.7	168.1	150.5
Total [2/]	535.2	500.1	483.5	459.7	455.3	404.0	274.8	229.3	1,478.9	1,593.1
10+ percent sound:										
3.0- 4.4	50.4	46.6	35.8	32.5	21.7	20.5	7.9	7.8	115.7	107.4
4.5- 7.4	46.1	42.7	104.4	95.3	95.3	90.7	48.9	48.9	294.8	277.6
7.5-10.4	117.7	89.2	166.8	146.6	208.2	177.8	110.8	96.0	603.4	509.6
10.5-13.4	91.3	88.2	111.7	88.7	119.6	92.9	69.4	48.6	392.1	318.4
13.5-16.4	95.3	51.8	80.9	60.9	12.7	5.1	23.8	6.8	212.7	124.6
16.5-19.4	16.3	16.3	36.6	7.3	0		36.6	11.0	89.6	34.7
19.5-22.4	102.3	79.8	27.4	5.5	50.0	15.9	50.0	15.9	229.6	117.2
22.5-25.4	0		0		29.9	3.0	0		29.9	3.0
25.5-28.4									0	
28.5-31.4									0	
31.5-34.4									0	
34.5+									0	
Slabs	117.1	97.7	45.9	43.1	8.4	8.4	1.7	1.7	173.1	151.0
Total [2/]	636.6	512.4	609.4	479.9	545.9	414.3	349.1	236.8	2,141.1	1,643.4

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 16—Average gross and net volumes of usable logging residue on study unit 4 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Soundness category and diameter class	Length class (feet)									
	4.0-7.9		8.0-13.9		14.0-20.9		21.0+		All classes	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
Inches	- - -

The utilization potential of the residue (natural and logging) was reduced as a result of the harvesting activities. Many pieces were broken and shattered when trees were felled and stem segments yarded. Slab volumes greatly increased in all units after logging (table 3 and fig. 1), indicating that shattering had occurred during the harvesting operations. Yarding of unutilized material also contributed to the increase in slab volume. In unit 1, more than 22 percent of the residue volume was in the form of slabs; in unit 2, 15 percent; in units 3 and 4, 6 and 8 percent. The defective condition of timber in units 1 and 2 (table 1) probably contributed heavily to the high generation of slabs in these units. According to study specifications, slab residues generated on units 1 and 2 (table 3) had little or no utilization potential (tables 13 and 14). In contrast, nearly 74 percent of the slab volume generated on unit 3 (table 3) could be used (table 15) and more than 7 percent on unit 4 (table 16); most of this volume was in pieces shorter than 14 feet.

Most of the YUM either met or exceeded the minimum specifications for utilization. When combined with the gross volume of usable residue left on the ground, the total potential usable residue for each unit was:

Unit	All residue	Total usable residue	
	(Cubic feet per acre)	(Cubic feet per acre)	(Percent of all residue)
1	4,388	1,530	35
2	3,779	2,081	55
3	4,790	3,124	65
4	4,101	2,506	61

Only in unit 1 was the volume of all residues (usable, unusable, and YUM) greater than the merchantable volume of logs removed (table 2). This anomaly is probably directly related to the decadent condition of the timber on unit 1, which produced only a small volume of YUM but an exceptionally large volume of unusable slabs (tables 3 and 13) and other residues (table 2). As on unit 1, the volume of slabs recorded on unit 2 (table 3) reflects the 39.9-percent defect in timber on this unit (table 1). Unlike unit 1, however, the merchantable volume of logs removed exceeded the volume of all residues remaining, even with an appreciable volume of YUM included. These data suggest that the amount and character of the residue remaining on a site depend heavily on the defective condition of the timber on that site and can change drastically with small changes in amounts of defect.

The piece count of usable residues per acre (excluding YUM) increased on all units after harvesting (table 2). Unit 1 had the largest increase with a piece count more than nine times greater per acre than that recorded prior to logging. The smallest increase occurred on unit 2 where the piece count more than tripled after logging. Most of the increases were in the shorter pieces in the smaller diameter classes. The number of pieces of usable residue per acre is summarized by soundness and by diameter and length classes for each unit before the logging operation (table 17) and after (tables 18-21).

Table 17—Average number of pieces per acre of usable residue on 4 study units before cable logging, by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Diameter class	Length class (feet) 4.0-7.9	8.0-13.9	14.0-20.9	21.0+	All classes
Inches					
Study unit 1:					
3.0- 4.4	5	0	1	1	7
4.5- 7.4	2	3	1	2	8
7.5-10.4	3	2	3	3	11
10.5-13.4	2	2	3	1	8
13.5-16.4	0	2	3	3	9
16.5-19.4	0	1	1	0	1
19.5-22.4	2	1	1	3	6
22.5-25.4					0
25.5-28.4	0	0	1	1	1
28.5-31.4	0	1	0	1	1
31.5-34.4					0
34.5+					0
Slabs					0
Total 2/	12	12	11	17	50
Study unit 2:					
3.0- 4.4	11	11	5	1	28
4.5- 7.4	12	11	6	7	37
7.5-10.4	5	7	8	6	26
10.5-13.4	3	1	4	5	13
13.5-16.4	2	4	3	3	11
16.5-19.4	0	0	1	1	2
19.5-22.4	0	2	1	1	4
22.5-25.4	0	0	1	1	2
25.5-28.4	2	0	0	1	3
28.5-31.4	0	1	0	1	2
31.5-34.4					0
34.5+	2	0	0	1	2
Slabs	0	2	1	0	2
Total 2/	36	39	28	30	133
Study unit 3:					
3.0- 4.4	31	8	6	1	46
4.5- 7.4	11	10	6	3	30
7.5-10.4	2	3	5	8	18
10.5-13.4	2	2	5	7	16
13.5-16.4	0	5	2	7	14
16.5-19.4	2	0	1	3	5
19.5-22.4	0	1	0	1	2
22.5-25.4	2	0	3	2	6
25.5-28.4	0	0	1	1	1
28.5-31.4	0	0	0	1	1
31.5-34.4	0	0	0	1	1
34.5+					0
Slabs	0	1	0	0	1
Total 2/	48	30	26	41	146
Study unit 4:					
3.0- 4.4	16	5	2	1	25
4.5- 7.4	8	5	4	5	22
7.5-10.4	1	5	7	10	34
10.5-13.4	3	3	2	7	15
13.5-16.4	0	3	2	5	9
16.5-19.4	1	0	1	3	5
19.5-22.4	0	1	0	2	3
22.5-25.4	1	0	0	1	3
25.5-28.4	0	0	0	1	1
28.5-31.4	0	0	0	2	2
31.5-34.4					0
34.5+					0
Slabs	0	1	0	1	2
Total 2/	30	24	19	38	110

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 50 percent sound, and yardable.

2/ Totals may be off because of rounding.

Table 18—Average number of pieces per acre of usable residue on study unit 1 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Soundness category and diameter class	Length class (feet) 4.0-7.9	8.0-13.9	14.0-20.9	21.0+	All classes
Inches					
75+ percent sound:					
3.0- 4.4	134	45	28	6	213
4.5- 7.4	51	27	27	16	121
7.5-10.4	10	3	4	6	23
10.5-13.4	3	2	1	1	7
13.5-16.4	2	1	0	0	2
16.5-19.4					0
19.5-22.4	2	0	0	0	2
22.5-25.4					0
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+					0
Slabs					0
Total 2/	202	78	60	29	369
50+ percent sound:					
3.0- 4.4	138	49	28	6	221
4.5- 7.4	58	28	29	16	131
7.5-10.4	10	5	5	7	26
10.5-13.4	8	2	2	2	14
13.5-16.4	3	2	0	0	5
16.5-19.4	0	1	0	0	1
19.5-22.4	2	0	1	0	2
22.5-25.4					0
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+					0
Slabs					0
Total 2/	219	87	63	32	401
30+ percent sound:					
3.0- 4.4	139	49	28	6	222
4.5- 7.4	61	28	29	16	134
7.5-10.4	10	6	8	7	30
10.5-13.4	11	4	3	2	20
13.5-16.4	3	2	0	1	7
16.5-19.4	0	1	1	1	2
19.5-22.4	2	0	1	0	2
22.5-25.4					0
25.5-28.4					0
28.5-31.4					0
31.5-34.4	2	0	0	0	2
34.5+					0
Slabs					0
Total 2/	228	90	68	34	420
10+ percent sound:					
3.0- 4.4	158	52	28	6	244
4.5- 7.4	65	31	31	17	144
7.5-10.4	20	11	9	7	47
10.5-13.4	13	7	6	2	29
13.5-16.4	3	5	2	1	11
16.5-19.4	0	2	2	2	5
19.5-22.4	2	0	1	1	3
22.5-25.4	0	1	0	0	1
25.5-28.4					2
28.5-31.4					0
31.5-34.4	2	0	0	0	2
34.5+					0
Slabs					0
Total 2/	263	109	77	37	486

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 19—Average number of pieces per acre of usable residue on study unit 2 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and diameter class	Length class (feet) 4.0-7.9	8.0-13.9	14.0-20.9	21.0+	All classes
Inches					
75+ percent sound:					
3.0- 4.4	75	37	19	8	139
4.5- 7.4	47	48	29	18	142
7.5-10.4	11	17	8	4	40
10.5-13.4	6	3	2	1	12
13.5-16.4	0	2	1	1	3
16.5-19.4	3	3	0	0	6
19.5-22.4	2	0	0	0	2
22.5-25.4	2	0	0	0	2
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+	2	0	0	0	2
Slabs	2	1	0	0	2
Total [2/]	148	110	58	33	350
50+ percent sound:					
3.0- 4.4	80	40	19	8	147
4.5- 7.4	56	53	31	20	159
7.5-10.4	16	22	9	5	52
10.5-13.4	6	5	3	1	16
13.5-16.4	3	3	1	1	8
16.5-19.4	3	3	0	0	6
19.5-22.4	2	0	1	0	3
22.5-25.4	2	1	0	0	2
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+	2	0	0	0	2
Slabs	2	1	0	0	2
Total [2/]	170	127	64	36	397
30+ percent sound:					
3.0- 4.4	84	42	20	8	153
4.5- 7.4	59	56	32	20	167
7.5-10.4	19	25	10	6	59
10.5-13.4	8	7	4	2	20
13.5-16.4	3	3	1	1	8
16.5-19.4	3	3	0	0	6
19.5-22.4	2	0	1	1	3
22.5-25.4	2	1	0	1	3
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+	2	0	0	0	2
Slabs	2	1	0	0	2
Total [2/]	181	136	68	38	424
10+ percent sound:					
3.0- 4.4	83	42	20	8	154
4.5- 7.4	62	57	32	20	171
7.5-10.4	22	25	10	6	63
10.5-13.4	8	7	5	2	22
13.5-16.4	3	3	2	2	10
16.5-19.4	3	3	0	0	6
19.5-22.4	2	0	1	1	3
22.5-25.4	2	1	1	1	3
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+	2	0	0	0	2
Slabs	2	1	0	0	2
Total [2/]	186	139	72	39	436

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 20—Average number of pieces per acre of usable residue on study unit 3 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and diameter class	Length class (feet) 4.0-7.9	8.0-13.9	14.0-20.9	21.0+	All classes
Inches					
75+ percent sound:					
3.0- 4.4	162	51	18	4	235
4.5- 7.4	45	45	28	9	127
7.5-10.4	41	32	25	9	107
10.5-13.4	24	11	8	2	45
13.5-16.4	6	6	0	0	12
16.5-19.4	3	0	0	0	3
19.5-22.4	6	0	0	0	6
22.5-25.4					0
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+					0
Slabs	40	7	1	0	48
Total [2/]	327	152	80	24	583
50+ percent sound:					
3.0- 4.4	168	54	18	4	244
4.5- 7.4	47	48	29	9	133
7.5-10.4	41	33	25	9	108
10.5-13.4	24	13	8	2	47
13.5-16.4	8	6	0	0	14
16.5-19.4	3	0	0	0	3
19.5-22.4	6	0	1	0	7
22.5-25.4					0
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+					0
Slabs	50	9	1	0	60
Total [2/]	347	163	82	24	616
30+ percent sound:					
3.0- 4.4	173	55	19	4	251
4.5- 7.4	47	51	30	9	137
7.5-10.4	43	33	26	9	111
10.5-13.4	24	13	9	2	48
13.5-16.4	8	6	1	0	15
16.5-19.4	3	0	0	0	3
19.5-22.4	6	0	1	0	7
22.5-25.4					0
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+					0
Slabs	56	9	1	0	66
Total [2/]	360	167	87	24	638
10+ percent sound:					
3.0- 4.4	180	57	19	4	260
4.5- 7.4	47	52	30	9	138
7.5-10.4	54	37	29	9	129
10.5-13.4	24	16	10	3	53
13.5-16.4	17	8	1	1	27
16.5-19.4	3	2	0	1	6
19.5-22.4	8	1	1	1	11
22.5-25.4	0	0	1	0	1
25.5-28.4					0
28.5-31.4					0
31.5-34.4					0
34.5+					0
Slabs	50	9	1	0	70
Total [2/]	393	182	92	28	695

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 21—Average number of pieces per acre of usable residue on study unit 4 after cable logging, by soundness category and by diameter and length classes, Pansy Creek drainage, Mount Hood National Forest 1/

Soundness category and diameter class	Length class (feet)				
	4.0-7.9	8.0-13.9	14.0-20.9	21.0+	All classes
Inches					
75+ percent sound:					
3.0- 4.4	268	50	13	2	333
4.5- 7.4	96	40	17	8	161
7.5-10.4	31	26	5	1	63
10.5-13.4	16	7	1	1	25
13.5-16.4	8	2	1	1	12
16.5-19.4	10	1	0	0	11
19.5-22.4	1	1	0	0	2
22.5-25.4	1	0	0	0	1
25.5-28.4	3	0	0	0	3
28.5-31.4	0	1	0	0	1
31.5-34.4	3	0	0	0	3
34.5+					0
Slabs	8	0	0	0	8
Total 2/	445	128	37	13	623
50+ percent sound:					
3.0- 4.4	273	50	13	2	338
4.5- 7.4	105	42	18	8	173
7.5-10.4	39	28	8	1	76
10.5-13.4	18	9	1	1	29
13.5-16.4	10	3	1	1	15
16.5-19.4	10	1	0	0	11
19.5-22.4	3	1	0	0	4
22.5-25.4	1	1	0	0	2
25.5-28.4	3	0	0	0	3
28.5-31.4	0	1	0	0	1
31.5-34.4	3	0	0	0	3
34.5+					0
Slabs	10	0	0	0	10
Total 2/	475	136	41	13	665
30+ percent sound:					
3.0- 4.4	274	51	13	2	340
4.5- 7.4	106	45	18	8	177
7.5-10.4	46	30	9	1	86
10.5-13.4	19	9	1	1	30
13.5-16.4	10	3	2	2	17
16.5-19.4	10	2	1	1	14
19.5-22.4	3	1	0	0	4
22.5-25.4	1	1	0	0	2
25.5-28.4	3	0	0	0	3
28.5-31.4	0	1	0	0	1
31.5-34.4	3	0	0	0	3
34.5+					0
Slabs	12	0	0	0	12
Total 2/	487	143	44	15	689
10+ percent sound:					
3.0- 4.4	279	52	13	2	346
4.5- 7.4	111	46	18	8	183
7.5-10.4	57	30	11	3	100
10.5-13.5	21	10	1	1	33
13.5-16.4	10	6	3	1	20
16.5-19.4	10	2	1	1	14
19.5-22.4	3	1	0	0	4
22.5-25.4	1	1	0	0	2
25.5-28.4	3	0	0	0	3
28.5-31.4	0	1	0	0	1
31.5-34.4	3	0	0	0	3
34.5+					0
Slabs	15	1	0	0	17
Total 2/	513	150	46	16	725

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Specifications for yarding unutilized material (table 1) influenced the distribution of usable material remaining on the units. Minimum specifications for YUM on unit 4 included some residues that were excluded as YUM on units 1, 2, and 3. As expected, the smaller diameter specification for removing YUM from unit 4 resulted in a greater reduction in the percentage of material remaining in this size category, both in volume and piece count, for the site (table 22). Because YUM yarding removed the larger pieces of unutilized material from the logging site, the volume of usable residue remaining was predominantly in pieces not meeting YUM specifications.

Logging residue that was at least 50 percent sound, 8 inches and larger in diameter, and at least 8 feet long probably meets or exceeds specifications for pulp or utility logs. Volume of usable residue (tables 13-16 and fig. 1) and number of pieces (tables 18-21) meeting these specifications on each unit were:

Unit	Volume		Pieces	
	(Cubic feet per acre)	(Percent of usable residue)	(Number)	(Percent of usable residue)
1	309	21	25	5
2	572	37	55	13
3	856	40	97	14
4	467	26	57	8

These estimates do not include the YUM material meeting these specifications that was removed during the harvesting operation.

The volumes of usable logging residues on each unit by soundness and material handling class are presented in tables 23-26. About 80 percent of the gross volume of usable residue on unit 1 was from felled trees, nearly 62 percent on unit 2, 68 percent on unit 3, and 61 percent on unit 4. Almost 54 percent of these amounts was bucked from longer pieces on unit 1, 45 percent on unit 2, 42 percent on unit 3, and 46 percent on unit 4. The lower average soundness of usable residue from felled trees on unit 1 (table 23), compared with the soundness of the usable residue on units 2, 3, and 4 (tables 24-26), suggests that the decadent condition of the timber on unit 1 predisposed the trees to produce higher proportions of residue from felled trees and of residue bucked from longer pieces. Of the downed residue remaining on the unit, about 9 percent of the volume had been bucked from longer pieces on unit 1, 14 percent on unit 2, 6 percent on unit 3, and 19 percent on unit 4.

Of the usable residue on unit 1, nearly 45 percent was bucked; on unit 2, 33 percent; on unit 3, 30 percent; and on unit 4, 35 percent. For the four units combined, more than 35 percent of the usable residue volume was bucked from longer pieces. This class of residue could have been easily reduced in volume by modifying guidelines for bucking whereby the practices of long butting and bucking out submerchantable or defective segments and broken log ends are restricted. Material that would otherwise be bucked from longer pieces would be left intact and be yarded with the merchantable logs or with the YUM material. This procedure would minimize the volume of bole residue left on the site.

Table 22—Volume and pieces of usable residue on 4 study units after cable logging, by 2 size groups, Pansy Creek drainage, Mount Hood National Forest 1/

Residue size group	Study unit	Volume of usable residue per acre		Pieces of usable residue per acre	
		Within size group	Percent of total	Within size group	Percent of total
		Cubic feet		Number	
7.5-inch d.i.b. or larger on large end, 8 feet long or longer	1	837.5	56.9	57	11.7
	2	819.0	53.6	70	16.1
	3	1,134.8	53.0	121	17.4
	4	765.3	42.2	72	9.9
10.5-inch d.i.b. or larger on large end, 8 feet long or longer	1	637.3	43.3	30	6.2
	2	569.9	37.3	29	6.7
	3	648.8	30.3	46	6.6
	4	545.9	30.1	38	5.3

1/ Usable residue includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 23—Average gross and net volumes of usable residue on study unit 1 after cable logging, by soundness category and material handling class, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		- - - -Percent- - - -	
75+ percent sound:				
Felled and bucked	310.4	307.4	99.0	49.5
Felled and broken	305.1	292.2	95.8	48.7
Down and bucked	0			
Down and broken	11.5	10.2	88.8	1.8
Total[2/]	627.0	609.8	97.3	100.0
50+ percent sound:				
Felled and bucked	363.3	337.3	92.8	44.7
Felled and broken	359.2	323.3	90.0	44.2
Down and bucked	25.4	14.1	55.3	3.1
Down and broken	65.0	37.0	56.9	8.0
Total[2/]	813.0	711.6	87.5	100.0
30+ percent sound:				
Felled and bucked	527.0	392.4	74.5	49.8
Felled and broken	414.4	341.8	82.5	39.2
Down and bucked	25.4	14.1	55.3	2.4
Down and broken	91.4	45.2	49.5	8.6
Total[2/]	1,058.2	793.6	75.0	100.0
10+ percent sound:				
Felled and bucked	630.5	408.1	64.7	42.8
Felled and broken	541.8	358.7	66.2	36.8
Down and bucked	25.4	14.1	55.3	1.7
Down and broken	274.2	61.1	22.3	18.6
Total[2/]	1,471.8	841.8	57.2	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 24—Average gross and net volumes of usable residue on study unit 2 after cable logging, by soundness category and material handling class, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		Percent	
75+ percent sound:				
Felled and bucked	385.4	379.7	98.5	39.0
Felled and broken	403.1	393.5	97.6	40.8
Down and bucked	46.3	39.2	84.8	4.7
Down and broken	154.1	135.8	88.1	15.6
Total [2/]	988.8	948.2	95.9	100.0
50+ percent sound:				
Felled and bucked	419.6	397.5	94.7	34.1
Felled and broken	477.0	438.0	91.8	38.8
Down and bucked	55.1	44.4	80.6	4.5
Down and broken	279.1	213.0	76.3	22.7
Total [2/]	1,230.8	1,092.9	88.8	100.0
30+ percent sound:				
Felled and bucked	420.8	398.0	94.6	29.8
Felled and broken	490.7	443.4	90.4	34.7
Down and bucked	61.8	46.4	75.1	4.4
Down and broken	440.6	268.4	60.9	31.2
Total [2/]	1,413.9	1,156.1	81.8	100.0
10+ percent sound:				
Felled and bucked	423.1	398.2	94.1	27.7
Felled and broken	522.9	449.7	86.0	34.2
Down and bucked	80.5	48.9	60.8	5.3
Down and broken	501.6	279.5	55.7	32.8
Total [2/]	1,528.0	1,176.4	77.0	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 25—Average gross and net volumes of usable residue on study unit 3 after cable logging, by soundness category and material handling class, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		-Percent-	
75+ percent sound:				
Felled and bucked	589.3	588.5	99.9	39.0
Felled and broken	776.1	768.8	99.1	51.3
Down and bucked	6.9	5.8	84.8	.5
Down and broken	140.6	117.5	83.6	9.3
Total [2/]	1,512.9	1,480.8	97.9	100.0
50+ percent sound:				
Felled and bucked	600.4	594.1	98.9	35.8
Felled and broken	789.7	777.1	98.4	47.1
Down and bucked	25.2	15.0	59.5	1.5
Down and broken	260.3	182.4	70.1	15.5
Total [2/]	1,675.7	1,568.5	93.6	100.0
30+ percent sound:				
Felled and bucked	606.1	596.3	98.4	34.7
Felled and broken	796.4	779.0	97.8	45.5
Down and bucked	30.9	16.7	54.1	1.8
Down and broken	315.6	201.1	63.7	18.0
Total [2/]	1,748.9	1,593.1	91.1	100.0
10+ percent sound:				
Felled and bucked	606.1	596.3	98.4	28.3
Felled and broken	849.7	788.2	92.8	39.7
Down and bucked	37.7	18.1	47.9	1.8
Down and broken	647.6	240.7	37.2	30.2
Total [2/]	2,141.1	1,643.4	76.8	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Table 26—Average gross and net volumes of usable residue on study unit 4 after cable logging, by soundness category and material handling class, Pansy Creek drainage, Mount Hood National Forest [1/]

Soundness category and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		-Percent-	
75+ percent sound:				
Felled and bucked	495.5	488.0	98.5	40.3
Felled and broken	552.1	547.5	99.2	44.9
Down and bucked	85.6	77.2	90.2	7.0
Down and broken	97.2	82.9	85.3	7.9
Total [2/]	1,230.3	1,195.6	97.2	100.0
50+ percent sound:				
Felled and bucked	504.6	493.5	97.8	35.4
Felled and broken	583.7	568.1	97.3	41.0
Down and bucked	94.7	82.7	87.3	6.7
Down and broken	240.5	162.2	67.4	16.9
Total [2/]	1,423.5	1,306.4	91.8	100.0
30+ percent sound:				
Felled and bucked	504.6	493.5	97.8	30.4
Felled and broken	593.0	571.8	96.4	35.7
Down and bucked	133.9	98.3	73.4	8.1
Down and broken	430.0	231.0	53.7	25.9
Total [2/]	1,661.6	1,394.7	83.9	100.0
10+ percent sound:				
Felled and bucked	504.6	493.5	97.8	27.8
Felled and broken	593.0	571.8	96.4	32.7
Down and bucked	133.9	98.3	73.4	7.4
Down and broken	582.0	253.0	43.5	32.1
Total [2/]	1,813.5	1,416.7	78.1	100.0

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

2/ Totals may be off because of rounding.

Conclusions

This investigation presents results based on a case study of a particular cable logging operation. Inferences that can be drawn from these results are unique to this study and may not necessarily apply to other cable operations. The information generated, however, can provide a basis on which forest land managers can evaluate logging operations for production of residue, its reduction, characteristics, volumes, and potential uses. Results of this study also give some indication of the fuel loading a land manager can expect from similar logging operations. The impact on the character and volume of the residue resulting from a change in utilization either from changes in the market or in logging requirements (for example, yarding unutilized material) can also be evaluated.

As expected, YUM yarding reduced the volume of large residue in the study units. The volume and distribution of pieces of usable residue were influenced by the contractual specifications for yarding unutilized material. The amount and character of the residue remaining on the sites were also influenced by the defect in the timber on the site; both changed drastically with a small change in amount of defect.

Results suggest that even with YUM yarding, a substantial volume of residue will still remain on the logging sites. Though much of this residue is usable according to our specifications, its removal and utilization will continue to be a problem for land managers. We found, however, that a considerable volume of the usable residue could have been removed if bucking procedures were modified. Much of the usable residue remaining on the site had been bucked from longer pieces. These could have been removed if left intact with the merchantable log or as part of the pieces removed as YUM.

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The volume and character of woody material on the ground in four old-growth Douglas-fir cutting units in the Cascade Range in Oregon were determined before and after harvesting by cable and yarding of unutilized material (YUM). Total volume of residue increased after logging in all units. Coarse residues were reduced by YUM yarding. Small changes in the defect condition of the timber can drastically affect the amount and character of the residues remaining on the site. Modifying bucking procedures can result in the removal of a considerable volume of usable residue.

Keywords: Residue management, residue treatment, logging effects, cable logging, old-growth stands, Douglas-fir, *Pseudotsuga menziesii,* Oregon (Cascade Range), Cascade Range—Oregon.

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Wrenching Douglas-Fir Seedlings In August: Immediate But No Lasting Effects

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Abstract

Stein, William I. Wrenching Douglas-fir seedlings in August: immediate but no lasting effects. Res. Pap. PNW-317 Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 12 p.

Effects of wrenching Douglas-fir seedlings in August of their second season in the D. L. Phipps State Forest Nursery, Elkton, Oregon, were determined by periodic samplings to learn of changes in phenological, morphological, and growth characteristics. Initial effects of wrenching moderated by January when seedlings were lifted; both wrenched and unwrenched seedlings had grown substantially larger. Survival and growth of seedlings were good during the first 5 years after outplanting in droughty skeletal soil on southeast and northeast slopes in the South Umpqua River drainage of southwestern Oregon, and no significant differences were found between wrenched and unwrenched seedlings. A difference in total tree height on the two slopes was caused by greater browsing on the southeast slope.

Keywords: Regeneration, wrenching, nursery practices, seedling growth, browsing (-regeneration, Douglas-fir, *Pseudotsuga menziesii*.

Summary

Responses of Douglas-fir seedlings in the nursery and after outplanting were determined following a single wrenching in August of their second season. It was premised that wrenching in early August would favorably influence root morphology and conditioning of seedlings, yet avoid the drastic growth reductions that often result from wrenching earlier in the growing season.

Seedlings used in the study had been grown following standard production practices at the D. L. Phipps State Forest Nursery, Elkton, Oregon, from seed obtained in seed zone 492 in the South Umpqua River drainage. During late summer and early autumn, wrenched and unwrenched seedlings were sampled at intervals from single bed segments for measurement of seedling size and for growth tests in a greenhouse and in raised beds outdoors. The entire bed of nursery stock was lifted in mid-January 1977; samples were again taken for measurement and growth tests, but in addition, 100 wrenched and 100 unwrenched seedlings were planted immediately on two droughty sites in skeletal soil of the Beekman series near Days Creek, Oregon.

Top and root status of wrenched and unwrenched seedlings differed 24 days after wrenching, and their subsequent phenology and growth did not proceed in parallel through late summer, autumn, and early winter. Growth of wrenched seedlings slowed down for a brief period and then resumed vigorously in early autumn whereas growth and hardening of unwrenched seedlings proceeded more steadily. Active root growth was found on wrenched and unwrenched seedlings at most sampling dates.

At first, shoot length of wrenched seedlings was shorter, shoots and roots were lighter, and number of lateral roots over 1 cm (0.4 in) long was less than for unwrenched seedlings. However, 145 days later, wrenched seedlings had longer shoots and a lower shoot:root ratio, but were similar to unwrenched seedlings in other respects. Large changes occurred in size of both wrenched and unwrenched seedlings

between late August and mid-January: linear regression equations describe these changes for six seedling attributes. The greatest change was a fivefold increase in ovendry weight of roots for wrenched seedlings.

Growth of seedlings transplanted to pots and raised beds indicated that both wrenching and lifting time were important influences. Growth of wrenched seedlings from the first two samplings was less than of unwrenched seedlings; differences for later samplings narrowed. The later in the season both wrenched and unwrenched seedlings were lifted, the greater their subsequent growth. Seedlings lifted in January also flushed earliest and most vigorously.

There was no difference in 5-year field survival and growth of wrenched and unwrenched seedlings. Survival was 90 percent on the southeast slope and 85 percent on the northeast slope. Seedlings averaged nearly 1 m tall (3.2 ft) and 14 mm (0.5 in) in diameter at 30 cm (12 in) above mean ground level. A significant difference in seedling height on the two slopes was found to be the result of browsing. Unbrowsed trees were the same height on both slopes, but total height of browsed trees was significantly lower on the southeast slope.

Nearly all studies of wrenching effect have reported that wrenching alters growth and physiology of Douglas-fir, but its influence on field performance has ranged from highly favorable to unfavorable. Wrenching is only one of the nursery practices that, in combination, conditions seedlings for outplanting. Factorial studies are in progress that test the combined effects of nursery practices In successive crops and outplantings.

Introduction

Production techniques used in the nursery can drastically influence the physical and physiological characteristics of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings. Several studies in the past decade have investigated the effects of seedbed density, undercutting, and irrigation practices on seedling size, characteristics, and performance (Duryea and Lavender 1982; Edgren 1976; Koon and O'Dell 1977; Menzies 1980; Tanaka and others 1975, 1976; Van Den Driessche 1983). In this study, responses of Douglas-fir seedlings in the nursery and after outplanting in skeletal soils were determined following a single wrenching in August of the second season.

Interest in wrenching Douglas-fir was stimulated in the Pacific Northwest by the improved survival and growth of Monterey pine (*Pinus radiata* D. Don) that was obtained using this practice in New Zealand (Dorsser and Rook 1972; Rook 1969, 1971). Wrenching involves passing a tilted blade or an oscillating bar under the seedbed to sever seedling roots and aerate the soil. The intended effects are to slow seedling height growth, stimulate lateral root development, and attain better balance between tops and roots. Key factors that influence wrenching results include initial size of seedlings, wrenching depth, and timing relative to stage of seedling development and to date of lifting. It was premised that wrenching in early August would favorably influence root morphology and conditioning of seedlings, yet avoid the drastic growth reductions that often result from wrenching earlier in the growing season.

Methods

Seedling Production

Seedlings used in the study were grown at the D. L. Phipps State Forest Nursery at Elkton, Oregon. Origin of the seed was from the 610-m (2,000-ft) elevation in seed zone 492 on lands managed by the Bureau of Land Management, U.S. Department of the Interior, in the South Umpqua River drainage southeast of Roseburg, Oregon.

The nursery's usual first- and second-year production practices were applied in growing seedlings from this lot. During the 1976 season, beds of seedlings were undercut at 15 cm (6 in) in late April, vertically root pruned in early June, and fertilized with 303 kg/ha (250 lbs/ac) of 27-12-0 fertilizer in April and May. Seedlings were watered sufficiently in the first half of the growing season to foster height growth. They developed at moderate bed density, about 323/m^2 (30/ft^2). On August 2, 1976, 15.2 lineal m (50 lineal ft) of nursery bed containing lot 492 were wrenched at the 18-cm (7-in) depth with an oscillating wrenching blade. A 15.2-m segment of the same bed was left unwrenched for comparison. The two adjoining segments were selected for their similarity in size and density of seedlings. Moisture stress in the wrenched seedlings averaged 12.25 bars before dawn the next day. As a general practice, Phipps Nursery relieved stresses over 12 bars by watering; thus, the entire bed of seedlings was irrigated for 2 hours on August 3.

Size Determinations

During late summer and early autumn, wrenched and unwrenched seedlings were sampled at intervals—on August 26, September 14, October 5, and October 29. Another sample was taken on January 18, 1977, when the entire bed of seedlings was lifted. On the first four dates, seedlings were dug with a tile spade; on the final date, they were loosened by machine at the 25-cm (10-in) depth. At each lifting, trees were taken from 4 well-spaced points in the wrenched or unwrenched bed segment separately and systematically allotted to 10-tree subsamples. Each subsample (bundle) received a nearly equal number of seedlings from each sampling point.

Roots of bundled trees were pruned to a 25-cm (10-in) length. Bundles of trees were then randomly designated for different purposes—measurement of seedling size, growth test in a greenhouse and in a raised bed outdoors and, for seedlings of the January lifting only, a test planting in the forest. Bundles of seedlings were put in plastic bags and transported to Corvallis, Oregon, or to the field in chests that were cooled with ice in warm weather.

Forty wrenched and 40 unwrenched seedlings from each lifting were measured for shoot length and stem diameter, counted for number of lateral roots 1 cm (0.4 in) or longer, and observed for presence of a terminal bud, light green foliage on terminal or lateral tips, and actively growing white roots. Shoot length in centimeters was determined by measuring from the base of the terminal bud to the root collar. The root collar was defined as located 1 cm (0.4 in) below the cotyledonal scars.

Stem diameter was measured to the nearest tenth of a millimeter at the root collar. The first 20 seedlings of each group were dried at 70°C (158°F) in a drying oven for 48 hours. Ovendry weight of top and root was determined to the nearest 0.01 gram, and shoot:root ratio (ovendry weight basis) was later calculated for each of these seedlings. All size data were summed, differences between treatment means for single dates and for all dates together were tested by analysis of variance, and changes over time were examined by regression techniques.

Growth Tests

Promptly after each lifting, 20 wrenched and 20 unwrenched seedlings were potted, and the pots were placed in random arrangement on a greenhouse bench. Large fiber pots were used, and 10 seedlings of a single treatment were planted in each one. The seedlings were maintained under well-watered greenhouse conditions from time of potting until May 13, 1977; observations on phenology and survival were made on March 3, March 22, and April 28, 1977. Height growth on seedlings lifted in January 1977, nearly all of whose terminal buds flushed normally, was measured on May 13, 1977. Observations then ended on these four pots of seedlings.

Potted seedlings of the earlier four liftings, whose terminals did not flush for lack of chilling, were subjected to a 60-day chilling period at 1°C (34°F) in an unlighted cooler and then placed outdoors and watered regularly for the remainder of the growing season. Survival and the 1977 growth response of the chilled seedlings was measured the next spring on May 17, 1978.

Twenty wrenched and twenty unwrenched seedlings from each lifting were also planted promptly in two raised outdoor beds, ten of a single treatment per row. The seedlings were watered just enough in late summer and autumn to prevent drought damage. They overwintered outdoors, and their appearance and flushing were observed on March 4, March 25, and May 3, 1977. Seedlings were watered regularly during the growing season of 1977. Their survival and height growth were determined on October 5, 1977. Treatment and lifting time differences in shoot growth data for these seedlings, and also for those of potted seedlings, were compared by analysis of variance and regression methods.

Two hundred seedlings from the January lifting were planted the same day on two field sites located southeast of Roseburg, Oregon, in Township 31 South, Range 4 West, Section 13, Willamette Meridan, on Bureau of Land Management lands. One hundred trees were planted on each site in a 2.4- x 2.4-meter grid (8 x 8 ft). Wrenched trees were planted at half the planting spots and unwrenched trees at the rest as randomly designated in advance. Two planters planted the trees; each planted wrenched and unwrenched trees as designated for individual spots in the rows. Trees were planted following normal good practice and were not shaded or otherwise protected. The weather was clear and sunny, but chilly, especially late in the afternoon on the northeast slope. Tree survival was first checked on May 25, 1977. Survival and initial and first-year height were determined on June 21, 1978; second-year survival and height on December 4, 1978; and fifth-year survival, height, and stem diameter on October 27, 1981. Growth data were tested by analysis of variance for differences due to treatment, slope, and browsing.

Both planting sites are located near 640-m (2,100-ft) elevation on soil of the Beekman series. This is a skeletal soil of the Klamath Mountains, moderately deep, very gravelly, loamy, and well drained, that originated from sedimentary and metamorphic rocks (Wert and others 1977). Average annual precipitation at the study sites is about 122 cm (48 in) with 13 cm (5 in) falling in the dry season, May through September (Froehlich and others 1982, McNabb and others 1982). One of the plantings was made on a moderately steep (40- to 50-percent) southeast slope (fig. 1), the other on a very steep (60- to 85-percent) northeast slope (fig. 2). Both areas had been clearcut and logged in the spring and summer of 1976, and slash was broadcast burned in autumn. The areas supported an open mixed-conifer stand of site IV quality, largely Douglas-fir with scattered incense-cedars (*Libocedrus decurrens* Torr.), and an understory of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Pacific madrone (*Arbutus menziesii* Pursh), and giant chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.

Perennial woody vegetation of variable density developed on these sites in competition with the Douglas-firs (fig. 2). After five years, the most prominent species included Pacific rhododendron (*Rhododendron macrophyllum* D. Don ex G. Don), Pacific madrone, giant chinkapin, bracken fern (*Pteridium aquilinum* (L.) Kuhn.), salal (*Gaultheria shallon* Pursh), trailing blackberry (*Rubus ursinus* Cham. & Schlecht.), snowbrush ceanothus (*Ceanothus velutinus* Dougl.), ocean spray (*Holodiscus discolor* (Pursh) Maxim.) and manzanita (*Arctostaphylos* sp.). Red alder (*Alnus rubra* Bong.), evergreen huckleberry (*Vaccinium ovatum* Pursh), willow (*Salix* sp.), sword fern (*Polystichum munitum* (Kaulf.) Presl), and whipplevine (*Whipplea modesta* Torr.) were more evident on the northeast slope than on the southeast slope. Such species as salal, bracken fern, and trailing blackberry were also more sparse and shorter on the southeast slope.

Figure 1.—The southeast slope was largely bare of vegetation in May 1977, 4 months after trees were planted. A clump of beargrass (*Xerophyllum tenax* (Pursh) Nutt.) is in the left foreground.

Figure 2.—A moderate cover of annual and perennial vegetation had developed on the steep northeast slope by June 1978.

Results

Phenological Changes

Top and root status of wrenched and unwrenched seedlings differed 24 days after wrenching, and the course of subsequent phenological events also differed through late summer and autumn (table 1). By late August, most wrenched seedlings had developed a terminal bud compared to only one-third of the unwrenched seedlings. By mid-September, nearly all seedlings sampled had terminal buds, but 3 weeks later only 60 percent of the wrenched seedlings had terminal buds. By late October, all seedlings had terminal buds, and such buds were universally present and prominent when seedlings were lifted in January.

Presence of light-green foliage at the tip of the terminal or lateral shoots, evidence of growth that occurred later than for other parts of the seedling, also reflected the phenological differences indicated by the terminal buds. Terminal shoots of wrenched seedlings were more active than those of unwrenched seedlings in October, but activity of lateral shoots was similar. Both wrenched and unwrenched seedlings showed some lighter green tips even in January.

Wrenched seedlings showed a high level of root activity at every sampling date except early October, whereas root activity of unwrenched seedlings increased from August onwards. Four out of five wrenched and unwrenched seedlings lifted in mid-January had root activity (five white root tips or more).

Size Changes

Composite samples taken from the wrenched and unwrenched segment of the nursery bed indicated that seedlings differed significantly in size in late August, 24 days after wrenching (table 2). Shoot length of wrenched seedlings was shorter, shoots and roots were lighter, and number of lateral roots over 1 cm (0.4 in) long was less. Shoot:root ratio of wrenched seedlings was significantly larger.

Table 1—Changes in phenology of wrenched and unwrenched seedlings in the nursery as shown by successive samplings

Phenological observation	Sampling date				
	8/26/76	9/14/76	10/5/76	10/29/76	1/18/77
	Percent occurrence (N=40)				
Terminal bud present:					
Wrenched	93	100	60	100	100
Unwrenched	35	98	95	100	100
Terminal foliage light green:					
Wrenched	25	3	48	0	8
Unwrenched	38	10	8	8	8
Lateral tip foliage light green:					
Wrenched	10	0	50	3	15
Unwrenched	30	10	43	8	5
Active root growth:					
Wrenched	78	100	43	93	80
Unwrenched	35	45	65	73	80

Table 2—Average shoot length, stem diameter, number of lateral roots, ovendry weight of tops and roots, and shoot:root ratio of wrenched and unwrenched seedlings at successive dates

Size attribute	Sampling date				
	8/26/76	9/14/76	10/5/76	10/29/76	1/18/77
Shoot length (cm):					
Wrenched	21.2	26.2	24.1	28.6	27.5
Unwrenched	23.9*1/	26.1	23.3	23.0**	25.1-
Stem diameter (mm):					
Wrenched	3.3	3.9	4.4	4.8	5.2
Unwrenched	3.5	4.3-	4.8*	4.5	5.1
Lateral roots (no.):					
Wrenched	8.1	9.6	7.9	10.5	15.6
Unwrenched	10.9*	8.3	7.6	7.6**	16.0
Shoot dry weight (gm):					
Wrenched	2.4	3.7	2.9	5.3	5.8
Unwrenched	3.5-	4.5	3.4	3.8-	5.6
Root dry weight (gm):					
Wrenched	0.7	1.6	1.5	2.2	3.4
Unwrenched	1.2**	1.5	1.4	1.7	3.0
Shoot:root ratio:					
Wrenched	3.5	2.4	2.1	2.5	1.7
Unwrenched	2.9**	3.2***	2.5**	2.3	1.9-

1 cm equals 0.394 in; 1 mm equals 0.0394 in; and 1 gm equals 0.035 oz.

1/Data pairs sharing a dash (-) or 1, 2, or 3 asterisks differ significantly at the 90-, 95-, 99-, and 99.9-percent probability levels, respectively.

When lifted for planting 145 days later, however, size of wrenched and unwrenched seedlings was similar in most respects (table 2). Furthermore, wrenched seedlings tended to be larger but not significantly so except in shoot length (93 percent probability). They also had a slight but significantly lower (93 percent probability) shoot:root ratio (1.7 vs. 1.9). Thus, the nearly equal-sized wrenched and unwrenched seedlings planted in the field had dormant tops and prominent terminal buds, and 80 percent of them had white growing root tips. Their physiological differences in January were unknown.

Very large changes occurred in size of both wrenched and unwrenched seedlings between late August and mid-January. The changes were largely systematic and, thus, appear to represent more than the random variation among successive destructive samplings.[1/] Regression analyses show that there was a significant change with time in each size attribute for both wrenched and unwrenched seedlings with one exception, shoot length of unwrenched seedlings (table 3). The amount of variation accounted for in the regressions differs by attribute, is generally greater for wrenched seedlings, and in all instances accounts for less than 40 percent of the total variation.

Magnitude of some size changes merits individual notice. The root dry weight of wrenched seedlings changed fivefold; for unwrenched seedlings, about half that much. Shoot dry weight of wrenched seedlings increased by a factor of 2.4, of unwrenched seedlings by 1.6. The shoot:root ratio of wrenched seedlings decreased from 3.5 to 1.7, for unwrenched seedlings from 2.9 to 1.9.

1/ Graphs illustrating changes in stem diameter, root dry weight, and shoot:root ratio were given in a preliminary report (Stein 1978).

Table 3—Regressions between size attributes and days elapsed since wrenching for wrenched and unwrenched seedlings

Regression formula				Statistical values[1/]	
Seedling attribute =	Constant	±	Coefficient (elapsed days)	Cumulative r^2	F ratio [2/]
Shoot length (cm):					
Wrenched seedlings	22.79	+	0.03 (days)	0.07	15.57***
Unwrenched seedlings	24.06	+	0.003 (days)	.00	.12
Stem diameter (mm):					
Wrenched seedlings	3.34	+	0.01 (days)	.26	70.45***
Unwrenched seedlings	3.80	+	0.01 (days)	.12	26.28***
Lateral roots (no.):					
Wrenched seedlings	6.31	+	0.05 (days)	.25	64.81***
Unwrenched seedlings	6.60	+	0.04 (days)	.19	46.59***
Shoot dry weight (gm):					
Wrenched seedlings	2.27	+	0.02 (days)	.18	21.29***
Unwrenched seedlings	3.17	+	0.01 (days)	.07	7.80**
Root dry weight (gm):					
Wrenched seedlings	0.50	+	0.02 (days)	.35	53.40***
Unwrenched seedlings	0.80	+	0.01 (days)	.26	34.39***
Shoot:root ratio:					
Wrenched seedlings	3.17	-	0.01 (days)	.33	48.46***
Unwrenched seedlings	3.23	-	0.01 (days)	.36	55.29***

1/ In formulas for shoot length, stem diameter and number of lateral roots, degrees of freedom are 1 and 198; for the rest, 1 and 98.

2/ 1 asterisk denotes significance of the regression F ratio at the 95-percent probability level; 2 asterisks, 99-percent; 3, 99.9-percent.

Growth in Pots

Most seedlings that were potted immediately after lifting and placed in a greenhouse survived, but time of lifting influenced their subsequent phenology and growth (table 4). In late April 1977, 97 percent of wrenched seedlings and 92 percent of unwrenched seedlings were alive. More wrenched than unwrenched seedlings had a healthy appearance. Many of the unhealthy appearing seedlings seemed to have a fungus infection on the needles; those lifted in August were most affected.

Terminal and lateral buds of wrenched and unwrenched seedlings that were lifted in January 1977 flushed vigorously by late April. By the same date, terminal buds had flushed on only 3 of the 147 seedlings still alive from the first 4 liftings and lateral buds had flushed on only 29. To find out if they were still capable of flushing, these nondormant seedlings of the first four liftings were subjected to 60 days of chilling, then set outdoors. All but four seedlings survived this harsh treatment, and 93 percent made some growth in 1977; three more that did not flush in 1977 flushed in the spring of 1978.

Growth of potted seedlings varied significantly with lifting date; the later the seedlings were lifted, the more growth (probability greater than 99.9 percent). Those lifted in January, which required no chilling, grew substantially more than any receiving a delayed chill treatment. Growth was also significantly greater for unwrenched seedlings (probability 99.5 percent).

Table 4—Response of wrenched and unwrenched seedlings potted immediately after lifting and maintained under growing conditions

Seedling response	Lifting date				
	8/26/76	9/14/76	10/5/76	10/29/76	1/18/77
Seedlings alive (%):					
Wrenched	85	100	100	100	100
Unwrenched	95	90	90	89	95
Healthy appearance (%):					
Wrenched	75	100	95	89	100
Unwrenched	20	85	80	78	90
Terminals buds flushed (%):					
Wrenched	5	0	0	5	100
Unwrenched	5	0	0	0	95
Lateral buds flushed (%):					
Wrenched	10	5	15	26	100
Unwrenched	20	10	25	39	95
Average shoot growth (cm):[1/]					
Wrenched	2.4	2.6	3.0	4.3	9.4
Unwrenched	3.1-[2/]	3.6-	3.5	5.9	10.3
Increment relative to initial shoot length (%):					
Wrenched	11	10	13	18	37
Unwrenched	14	14	18	24	41

1 cm equals 0.394 in.

[1/] Shoot growth for seedlings lifted 1/18/77 was determined 5/13/77, for the rest, 5/17/78.

[2/] Data pairs for average shoot growth sharing a dash (-) differ significantly at the 90-percent probability level.

Growth in Outdoor Beds

At the March 4, 1977, examination, when terminal buds were still tight, seedlings had a range of color—those of the January lifting were deep green; those of the August lifting were barely medium green. Unwrenched seedlings of the August, September, and October liftings were also darker green than were the wrenched seedlings lifted on the same dates.

All seedlings that survived the 1977 growing season flushed in the spring. Bud swelling was evident by March 25 for seedlings from all liftings except those in August and September. Those lifted in January flushed earliest and most vigorously: in fact, rows of these seedlings could be spotted readily in the May 3 examination by their uniform flushing and greater amount of new growth. There was slight evidence that wrenched seedlings flushed a bit sooner than unwrenched seedlings, particularly for seedlings lifted in late summer and autumn.

First-year survival and growth was good in the outdoor beds for seedlings of all liftings (table 5). As with potted seedlings, height growth varied significantly with lifting date (probability 99.5 percent); the later seedlings were lifted, the more growth. Height increment of seedlings ranged from one-third to one-half of the initial height. Relative growth of wrenched and unwrenched seedlings varied by date (probability of interaction, 93.3 percent). An adverse effect of wrenching on height growth was indicated for the earlier liftings, but growth trends then converged.

Table 5—First-year survival and average shoot growth of wrenched and unwrenched seedlings planted immediately after lifting in raised, outdoor beds

Seedling response	Lifting date				
	8/26/76	9/14/76	10/5/76	10/29/76	1/18/77
Seedlings alive (%):					
Wrenched	100	100	90	100	100
Unwrenched	80	80	95	90	95
Average shoot growth (cm):[1/]					
Wrenched	7.1	7.7	8.0	10.0	11.5
Unwrenched	8.8	9.2	9.4	9.7	10.1
Increment relative to initial shoot length (%):					
Wrenched	31	32	31	50	44
Unwrenched	46	39	39	48	47

1 cm equals 0.394 in.

[1/] Differences in average shoot growth for wrenched and unwrenched seedlings at individual dates are not significant at the 90-percent probability level.

Growth in the Field

Survival of wrenched and unwrenched seedlings was good on both northeast and southeast slopes (table 6). At the end of 5 years, 87.5 percent of the seedlings planted were alive—90 percent on he southeast slope and 85 percent on the northeast slope. Most of the mortality occurred in the first season—9 percent of the total seedlings died compared to 3.5 percent after the first season. Survival of wrenched seedlings averaged only 3 percent more than for unwrenched seedlings.

During the infrequent reexaminations, cause of mortality was not evident on most dead seedlings. Mortality was scattered throughout the grids and showed no obvious pattern. Stress soon after planting caused some mortality; incidental causes included burial from loose soil, heavy shading from brush competition, and being covered by fallen dead poles. Only five seedlings that died had been browsed.

Five years after planting, seedlings averaged just under 1 m (3.2 ft) in total height and nearly 14 mm (0.5 in) in diameter at 30 cm (12 in) above mean ground level (table 7). Heights and diameters of wrenched and unwrenched seedlings did not differ significantly at the 90-percent probability level; in fact, their average heights were identical. Total height of unwrenched seedlings tended to be slightly greater after the first year (probability 85 percent) but this initial advantage disappeared.

Total height of seedlings but not stem diameter tended to differ on the two slopes (probability 88 percent). Seedlings on the northeast slope averaged 102 cm (3.3 ft) in height; those on the southeast slope averaged 94 cm (3.1 ft).

Table 6—Field survival of wrenched and unwrenched seedlings in the first 5 years

Slope and treatment	Seedlings planted 1/77	Seedlings alive			
		5/77	6/78	12/78	10/81
	Number	Percent			
Southeast slope:					
Wrenched	50	98	94	94	92
Unwrenched	50	100	94	90	88
Northeast slope:					
Wrenched	50	96	90	88	86
Unwrenched	50	100	86	86	84
Total:					
Wrenched	100	97	92	91	89
Unwrenched	100	100	90	88	86
Average		98.5	91.0	89.5	87.5

Table 7—Periodic total height of wrenched and unwrenched seedlings and fifth-year average diameter

Slope and treatment1/	Total height				Stem diameter
	5/77	6/78	12/78	10/81	
	Centimeters				Millimeters
Southeast slope:					
Wrenched	24.2	29.6	37.4	94.2	13.1
Unwrenched	24.9	31.5	38.3	93.3	14.7
Northeast slope:					
Wrenched	24.2	28.1	35.8	101.7	13.1
Unwrenched	24.5	29.2	38.0	102.5	13.5
Total					
Wrenched	24.2	28.9	36.6	97.8	13.1
Unwrenched	24.7	30.4	38.2	97.8	14.1
Average and standard error	24.5 ± 0.5	29.6 ± 0.5	37.4 ± 0.7	97.8 ± 2.6	13.6 ± 0.5

1 cm equals 0.394 in; 1 mm equals 0.0394 in.

1/Differences between wrenched and unwrenched seedlings are not significant at the 90-percent probability level.

Effects of Browsing

Fifty-six percent of surviving seedlings were browsed one or more times in the first 5 years. Browsed seedlings averaged 95 cm (3.1 ft) tall, unbrowsed seedlings 102 cm (3.3 ft) tall (table 8); the probability of a real difference is 82 percent. A majority of browsing damage occurred the first year; 83 trees were rated as browsed in the first examination, 18 were judged to have sustained damage between the first and second examinations, and 25 between the second and final examinations. Severity of damage in terms of amount of top removed tended to be light to moderate.

There was no selective browsing of wrenched or unwrenched trees, based on fifth-year height averages. In terms of numbers, a few more wrenched than unwrenched trees were browsed.

Browsing varied significantly by slope, however. A larger percentage of the trees planted on the southeast slope were browsed than of those planted on the northeast slope (62 vs. 49 percent). On the southeast slope, the average height of browsed trees was significantly less (probability 97 percent) than of unbrowsed trees—88 cm (2.9 ft) vs. 104 cm (3.4 ft). Average height of browsed and unbrowsed trees did not differ significantly on the northeast slope—104 cm (3.4 ft) vs. 100 cm (3.3 ft).

It is noteworthy that the average height of unbrowsed trees on the southeast slope was equal to (perhaps even greater) than for unbrowsed trees on the northeast slope. Site conditions are often considered more severe on southeast than on northeast slopes.

Browsed and unbrowsed trees did not differ significantly in average diameter.

Table 8—Average total height at five years of unbrowsed and browsed, wrenched and unwrenched Douglas-firs

Slope and treatment[1/]	Unbrowsed Douglas-firs		Browsed Douglas-firs	
	Trees	Height	Trees	Height
	Number	Centimeter	Number	Centimeter
Southeast slope:				
Wrenched	15	107.5	31	87.8
Unwrenched	19	100.5	25	87.8
Northeast slope:				
Wrenched	21	96.6	22	106.5
Unwrenched	22	104.0	20	100.9
Total:				
Wrenched	36	101.1	53	95.6
Unwrenched	41	102.4	45	93.6
Total or average and standard error	77	101.8 ± 4.0	98	94.7 ± 3.5

1 cm equals 0.394 in.

[1/] Differences between wrenched and unwrenched seedlings are not significant at the 90-percent probability level.

Discussion and Conclusions

Field Performance

Five-year survival of planted Douglas-fir was high on the two field sites. These sites, located on skeletal soil of the Klamath Mountains, were selected for the study because they are commonly considered to be difficult to regenerate with Douglas-fir. Survival of unshaded seedlings was 90 percent on the southeast slope, slightly higher than on the nearby steep northeast slope, even though the percentage of trees browsed was also greater. Annual precipitation at Days Creek during 1977, when most mortality occurred, was near normal, but precipitation during the growing season was substantially higher than normal.[2/] Planting the seedlings the same day they were lifted from the nursery was the only exceptional practice used in the study. Other practices were those used routinely at the time: nursery stock of local source lifted and outplanted while dormant, sites prepared by broadcast burning after clearcutting, and no postplanting vegetation control. Study results indicate that Douglas-fir can be established readily on Beekman soils in some years, but how consistently must still be determined.

The light to medium browsing sustained by trees in this study seems of minor consequence. Few browsed trees died, and the 7-cm (2.8-in) average difference in total height of browsed and unbrowsed trees is not likely to be important in the long run. Biological understanding has been improved, however, by knowing that browsing can cause seedling growth capability to appear different on southeast and northeast slopes.

2/ Personal communication, Henry A. Froehlich, Oregon State University, Corvallis, July 27 and December 8, 1983.

Wrenching Effects

Growth, morphological, and phenological data provide evidence that wrenching seedlings once in August had some short-term negative effects, but these effects soon moderated. Wrenching appears to have slowed seedling growth temporarily but then it resumed in autumn months more actively and with somewhat different timing than for unwrenched seedlings. Seedlings transplanted soon after wrenching did not have as much shoot growth capacity as unwrenched seedlings. Survival capacity may have been improved for seedlings transplanted soon after wrenching; mortality differences were small, but seedlings appeared healthier. The minor shoot length and shoot:root ratio differences in favor of wrenched seedlings at time of field planting had no long-term effect on seedling survival and growth.

Results of this study add some insight to the debate on the merits of wrenching for improving field survival and growth of Douglas-fir. Even a single wrenching late in the season curtailed growth and altered the physiology of Douglas-fir seedlings, a finding consistent with results of most other, generally more drastic, wrenching regimes (Duryea and Lavender 1982, Koon and O'Dell 1977 Menzies 1980, Tanaka and others 1975, Van Den Driessche 1983). Wrenching did not improve field survival, however; a finding consistent with results reported by Duryea and Lavender (1982) and Menzies (1980), but at variance with findings of Koon and O'Dell (1977), Tanaka and others (1975, 1976), and Van Den Driessche (1983). Field growth of seedlings was not improved by wrenching, as reported also for at least part of the tests by Duryea and Lavender (1982), Menzies (1980), and Van Den Driessche (1983).

In this study, lack of a wrenching effect on seedling field survival and growth might be due to the favorable first-year growing season. Moisture stresses may not have become sufficiently high to bring out differences. On such droughty sites, however, some degree of moisture stress is likely even when rainfall in the pronounced dry season is well above average. There are other possible explanations. Sites were free of snow in January so planting was earlier than usual, roots were active, and seedlings might have had several months to stabilize before being subjected to critical moisture stresses. Koon and O'Dell (1977) reported that internal water stresses were different in wrenched and unwrenched seedlings only for the first 45 days after planting. Finally, wrenching might not have been severe enough to perpetuate its effects for more than 6 months. Data from seedlings lifted periodically indicated that growth in the nursery during autumn months moderated early differences between wrenched and unwrenched seedlings. Although lack of replication of the wrenching treatment limited some statistical comparisons, regression equations clearly showed that major changes in seedling size occurred between wrenching and final lifting date.

Lifting date deserves emphasis for two reasons. The more time that elapses between wrenching and lifting, the more chance there is for wrenching effects to diminish because of growth and physiological changes that occur in both wrenched and unwrenched seedlings. The degree of change is dependent on the nursery practices applied subsequent to wrenching, on the seasonal top and root growth pattern for the nursery, on the weather in the particular season, and perhaps on other factors. Lifting date also has an important direct influence on subsequent seedling growth. Both wrenched and unwrenched seedlings that were lifted before they were dormant subsequently made less shoot growth than those that were fully dormant.

Wrenching is only one of the nursery practices that help condition seedlings for outplanting. Effect of seedbed density has been given some attention in wrenching studies, but other factors, particularly the irrigation regime, need more consideration. Effects of the same wrenching schedule on successive nursery crops and on field performance in different years also need to be determined. Studies to fill some of these gaps are in progress.

Acknowledgments

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Effects of wrenching Douglas-fir seedlings in August of their second season in the D. L. Phipps State Forest Nursery, Elkton, Oregon, were determined by periodic samplings to learn of changes in phenological, morphological, and growth characteristics. Initial effects of wrenching moderated by January when seedlings were lifted; both wrenched and unwrenched seedlings had grown substantially larger. Survival and growth of seedlings were good during the first 5 years after outplanting in droughty skeletal soil on southeast and northeast slopes in the South Umpqua River drainage of southwestern Oregon, and no significant differences were found between wrenched and unwrenched seedlings. A difference in total tree height on the two slopes was caused by greater browsing on the southeast slope.

Keywords: Regeneration, wrenching, nursery practices, seedling growth, browsing (-regeneration, Douglas-fir, *Pseudotsuga menziesii.*

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Losses Associated With Douglas-Fir and True Fir Tops Killed by Western Spruce Budworm in Eastern Washington

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Abstract

Aho, Paul E. Losses associated with Douglas-fir and true fir tops killed by western spruce budworm in eastern Washington. Res. Pap. PNW-318. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 8 p.

A sample of 133 Douglas-firs (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and 69 true firs (*Abies* spp.) with dead tops caused by defoliation by the western spruce budworm (*Choristoneura occidentalis* Freeman) were felled, dissected, and examined for height loss and incidence and extent of decay. Height loss was negligible for trees with only the last year or two of their tops killed by defoliation because lateral branches quickly formed new tops. Height losses of trees severely damaged by top-kill averaged 4.3 feet for Douglas-fir and 4.4 feet for true firs, but some trees had new tops with an average length of 0.9 foot for the Douglas-firs and 1.1 feet for the true firs. Only three trees were infected by decay fungi, and associated loss of volume was negligible.

Keywords: Insect damage (-forest, increment (height), crown damage, decay (wood), heartwood rot, western spruce budworm, Douglas-fir, *Pseudotsuga menziesii,* true fir, *Abies* spp., Washington (eastern), eastern Washington.

Research Summary

From 1970 to 1979, the western spruce budworm (WSBW) (*Choristoneura occidentalis* Freeman) caused extensive damage on the Wenatchee and Okanogan National Forests in Washington by defoliating 1.2 million acres of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and true firs (*Abies* spp.). Severe defoliation often kills the tops of attacked trees. In this study, losses in height and losses caused by decay associated with defoliation of Douglas-fir and true fir tops by western spruce budworm are estimated. Estimates extrapolated from other studies of treetops killed by WSBW or tussock moth in other areas may not be applicable on these Forests.

A sample of 133 Douglas-firs from 14 stands and 69 true firs from 9 of these stands were studied to determine height and decay losses associated with top damage caused by defoliation by the WSBW. Negligible losses in height were observed for both species when only the last year or two of growth of treetops was killed. Lateral branches quickly assumed dominance and formed new tops. Height losses of trees severely damaged by top-kill averaged 4.3 feet for Douglas-fir and 4.4 feet for true firs. Regrowth of tops by lateral branches was about 1 foot for both species. Apparently lateral branches lower in the tree are less vigorous than those nearer the original treetop or trees with extensive top-kill were so severely damaged by the effects of defoliation that the laterals could not respond.

Only three of the sample trees with dead tops were infected by decay fungi. Average basal diameter of dead tops was less than 1 inch. Only 7 percent of all trees studied with top-kill had basal diameters larger than 2 inches. More than four-fifths of all the top-killed trees had been dead fewer than 6 years—too little time for extensive decay to develop. Only five dead tops, all true firs, had also been attacked by bark beetles.

Decay losses associated with dead tops should be low on the Wenatchee and Okanogan National Forests if conditions in most defoliated stands are similar to those in the 14 sampled stands.

Introduction

From 1970 to 1979, western spruce budworm (WSBW) (*Choristoneura occidentalis* Freeman) caused extensive damage on 1.2 million acres of Douglas-fir and true firs on the Okanogan and Wenatchee National Forests in Washington (Harvey 1982). Damage varied from minor defoliation to top-killing to tree mortality. An evaluation was conducted in 1980 to quantify stand volume losses caused by the WSBW infestation. Volume lost as dead tops in trees attacked by WSBW and from subsequent decay of living stems below dead tops has not been evaluated in Washington. In addition, height losses caused by top-killing and the portion of a "dead top" actually dead have not been quantified.

In Canada, Stillwell (1956) found 0.5 to 23 feet of decay in living crowns of balsam fir below tops killed by eastern spruce budworm 35 years earlier. In grand fir in Idaho, Ferrell and Scharpf (1982) found columns of decay typically from 2 to 3 feet long below tops killed by WSBW over 57 years. One dead top resulted in cull of the entire tree.

In a study of decay losses associated with tops killed by Douglas-fir tussock moth (*Orgyia pseudotsugata* McDonnough) defoliation, little deductible defect was associated with top-kill of white fir in California after 33 years (Wickman and Scharpf 1972). In 1979 in eastern Oregon and Washington, Aho and others found 4.8 percent of the gross cubic-foot volume decayed in living grand fir stems below tops killed 2 to 35 years before by tussock moth defoliation.

In this study, the losses in height and decay caused by WSBW top-killing Douglas-fir and true firs on the Okanogan and Wenatchee National Forests are estimated. Extrapolation of estimates from similar studies in other areas or States may not be applicable on these Forests. Tops that appeared to be dead were examined to determine what proportion were still alive.

Methods

The study was planned to be conducted in a randomly selected subsample of stands from a study conducted by Forest Pest Management (FPM) of the Pacific Northwest Region of the USDA Forest Service, "Effects of western spruce budworm infestation on stand volume on the Okanogan and Wenatchee National Forests." The data were to be tied to FPM's evaluation of the stands. Because the FPM stands could not be destructively sampled, similar stands close to those being evaluated by FPM had to be found.

Selection of Study Stands and Trees

From stands that were close to the FPM stands and that had been severely defoliated by the western spruce budworm up to 10 years before, 14 stands were sampled in the Okanogan and Wenatchee National Forests (table 1).

Inland Douglas-fir was a component of all stands sampled, whereas true firs occurred in only nine. True fir species were: grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), Pacific silver fir (*A. amabilis* Dougl. ex Forbes), and subalpine fir (*A. lasiocarpa* (Hook.) Nutt.).

Table 1—Douglas-firs and true firs with or without dead tops sampled in 14 stands attacked by western spruce budworm in the Wenatchee and Okanogan National Forests

Ranger District and stand	Douglas-fir tops			True fir tops		
	Not dead	Dead 1/	Not visible 2/	Not dead	Dead 1/	Not visible 2/
	Number of trees					
WENATCHEE NATIONAL FOREST						
Cle Elum Ranger District:						
Cooper Lake	1	5	2	0	6	3
Little Creek	0	5	3	0	5	3
Thorp Creek	0	6	3	0	4	3
Ellensburg Ranger District:						
First Creek	1	6	2	0	5	3
Porky Basin #1	1	3	4	1	6	2
Porky Basin #2	0	3	5	0	5	4
Leavenworth Ranger District:						
The Icicle	1	5	2	1	5	3
OKANOGAN NATIONAL FOREST						
Conconully Ranger District:						
Cabin Creek	3	4	5	0	0	0
Funk Mountain	1	5	3	3	4	1
Rusty Creek	6	8	2	0	0	0
State Cabin Road	3	5	1	1	5	2
Twisp Ranger District:						
Little Bridge Creek	1	8	8	0	0	0
Winthrop Ranger District:						
Goat Wall	1	8	7	0	0	0
Eightmile Creek	1	8	7	0	0	0
Total	20	79	54	6	45	24

1/ Dead top visible from ground before tree was felled.

2/ Dead top not visible until tree was felled and dissected.

Because data from this study were to be applied to standing trees examined by FPM field crews, it was important to note whether or not damaged tops could be seen before trees were felled. In most of the stands sampled, it was nearly impossible to differentiate between trees with healthy and dead tops while trees were standing, unless a spike top protruded above the live crown. Many trees had their tops killed in the past, but over time, a lateral branch had assumed dominance to form a new top. The dead tops, in most cases, were hidden from ground view in the live crown.

Attempts were made to locate three apparently healthy and five top-killed Douglas-fir and true firs in each stand sampled. Where only Douglas-fir or true fir occurred, the sampled was doubled (6 healthy and 10 top-killed) for the species present. In some stands, all trees with top-kill had to be sampled because of the small population of trees with visible damage. In most stands, however, selection could be made from a large number of trees with dead tops. A representative sample was selected from a range of trees based on size of trees and of top-kills.

Standing sample trees were carefully examined by use of binoculars to determine top damage, evidenced by spike, bayonet, forked, or crooked tops. If no damage was seen, the top was considered "healthy," even if the top was found to be dead after the tree was felled and dissected. Diameter of trees at breast height (4.5 feet) was measured, and other indicators of decay were noted while trees were still standing.

Dissection and Measurement of Trees

Selected trees were felled at a stump height of 6 inches and dissected into 16-foot logs to a top d.i.b. (diameter inside bark) of 4 inches (for cubic volume measurement) and to a top d.i.b. of 6 inches for trees 11.0 inches and greater in d.b.h. (diameter at breast height) to determine board-foot volume according to Aho and others (1979). Age of trees was determined by a ring count at stump height.

The height growth of trees without visible top damage was measured by yearly increments for the last 15 years in feet and tenths. Cuts were made at each node, and rings were counted to check ages determined earlier. By use of this system, the years when a tree did not grow in height (probably because of defoliation by the WSBW) could be determined.

For trees with top damage, the type of damage (broken, spike, bayonet, forked, crooked tops), height to the base of the dead top, basal diameter and length of the killed top, length and diameter of new leaders, secondary damage from insects, and extent of decay below and above the base of the dead tops were recorded. Each apparently dead top was carefully examined to see if the cambium and buds at the tips of lateral branches were actually dead. Length of live portions of "dead" tops was noted. The age (year of origin) of the top damage was determined by comparing ring counts from disks cut immediately below, at, and above the top-killed portion. Logs were further dissected to measure extent of decay from other causes.

Isolation of Decay Fungi

Culture blocks, about 27 cubic inches in size, were taken at the base of and just below the dead top and from wherever discoloration or decay was found, usually near other indicators. Blocks were placed in an ice chest or were refrigerated until they were taken to the laboratory. The blocks were split with a sterile chisel, and two small chips (about 3 mm^3) were aseptically removed and placed on malt agar slants in test tubes. The tubes were incubated on a bench at room temperature. The types of micro-organisms isolated were noted after an incubation of 6 weeks.

Decay Associated With Dead Tops

Basic data for the 133 Douglas-firs with top damage are summarized in table 2. The top damage in 54 trees was not visible when viewed from the ground (table 1). Only one dead top was infected by decay fungi (table 2). Loss from decay was negligible. The incidence of infection by decay fungi was probably limited by the small size of the tops and the recent origin of the damage. Average basal diameter was 0.5 inch, and age of dead tops was 5 years. Only 6 percent of the basal diameters of the tops killed were larger than 2 inches. Nearly 80 percent of the tops had been dead fewer than 6 years.

Five columns of decay, associated with injuries other than top damage, were found in the Douglas-firs (table 2). Cubic- and board-foot volumes lost because of these infections were small.

In the nine stands of true firs sampled, 69 trees with dead tops were studied. Only two tops were infected by decay fungi and, as with the Douglas-fir sample, loss of volume was small (table 3). Infection by decay fungi was probably low because of the small basal diameters, the recency of top-killing, and the low incidence of a secondary attack by beetles. Average diameter at the base of dead tops was 0.9 inch, and only six diameters (9 percent) were larger than 2 inches. Aho and others (1979), in a study of decay associated with grand fir tops killed by Douglas-fir tussock moth defoliation, found low levels of infection and decay in dead tops with basal diameters of less than 2 inches.

Average length of time the tops had been dead was 5 years (table 3). Only 11 tops (16 percent) were dead more than 5 years. The two top-kills infected by decay fungi were 8 and 11 years old.

Table 2—Basic data for 133 Douglas-firs top-killed by the western spruce budworm in 14 stands in the Wenatchee and Okanogan National Forests

Stand name	Trees with dead tops	Infected dead tops		Average diameter of tree		Average diameter of top-kill		Cubic-foot volume associated with top-kill			Board-foot volume associated with top-kill			Decay not associated with top-kill: Total infections	Decay not associated with top-kill: Cubic-foot volume		Decay not associated with top-kill: Board-foot volume	
								Gross	Decay	Decay	Gross	Decay	Decay		Total	Percent of gross	Total	Percent of gross
	No.	No.	%	D.b.h. In	Age Yr	Base In	Age Yr	Ft³		%	Board feet		%	No.	Ft³		Board feet	
Porky Basin #1	7	0	0	8.0	67	0.4	5	63.5	0	0	102	0	0	0	0	0	0	0
The Icicle	7	1	14	8.6	99	1.0	6	89.7	.1	.1	301	0	0	0	0	0	0	0
Porky Basin #2	8	0	0	9.7	74	.5	6	99.5	0	0	326	0	0	1	.1	.1	0	
Little Bridge Creek	16	0	0	12.2	92	.6	6	415.2	0	0	1,527	0	0	0	0	0	0	0
Eightmile Creek	15	0	0	11.1	126	.4	6	251.7	0	0	925	0	0	1	0.3	.5	18	1.9
Goat Wall	15	0	0	10.7	150	.3	6	197.9	0	0	506	0	0	3	.6	.3	7	1.4
State Cabin Creek	6	0	0	7.4	139	.1	3	27.7	0	0	0	0	0	0	0	0	0	0
Funk Mountain	8	0	0	8.4	68	.1	2	48.4	0	0	40	0	0	0	0	0	0	0
Cabin Creek	9	0	0	8.3	73	.1	3	64.6	0	0	0	0	0	0	0	0	0	0
Rusty Creek	10	0	0	9.3	75	.2	2	98.2	0	0	144	0	0	0	0	0	0	0
Cooper Lake	7	0	0	10.3	77	.8	3	94.7	0	0	163	0	0	0	0	0	0	0
Thorp Creek	9	0	0	9.7	92	1.3	4	104.9	0	0	139	0	0	0	0	0	0	0
First Creek	8	0	0	9.1	68	1.2	4	75.4	0	0	143	0	0	0	0	0	0	0
Little Creek	8	0	0	8.8	76	.5	4	72.9	0	0	217	0	0	0	0	0	0	0
Total or average	133	1	.8	9.8	95	.5	5	1,704	.1	0	4,533	0	0	5	2.0	.1	25	.6

Table 3—Basic data for 69 true firs top-killed by the western spruce budworm in 9 stands in the Wenatchee and Okanogan National Forests

Stand name	Trees with dead tops	Infected dead tops		Average diameter of				Cubic-foot volume associated with top-kill			Board-foot volume associated with top-kill			Decay not associated with top-kill				
				Tree		Top-kill									Cubic-foot volume		Board-foot volume	
				D.b.h.	Age	Base	Age	Gross	Decay	Decay	Gross	Decay	Decay	Total infections	Total	Percent of gross	Total	Percent of gross
	No.	No.	%	In	Yr	In	Yr	- - Ft^3 - -		%	Board feet		%	No.	- - Ft^3 - -		Board feet	
Porky Basin #1	8	1	12.5	9.5	60	1.2	6	94.1	0.5	0.5	309	3	1.0	2	0.3	0.3	0	0
The Icicle	8	0	0	8.4	105	1.1	8	74.3	0	0	0	0	0	4	.4	.4	0	0
Porky Basin #2	9	1	11.1	9.5	76	1.1	4	69.7	.1	0	205	0	0	5	.5	.5	1	.7
State Cabin Road	7	0	0	7.3	48	.2	1	38.1	0	0	0	0	0	0	0	0	0	0
Funk Mountain	5	0	0	7.2	68	.3	3	21.8	0	0	0	0	0	1	.1	.5	0	0
Cooper Lake	9	0	0	7.7	71	.4	3	62.7	0	0	0	0	0	0	0	0	0	0
Thorp Creek	7	0	0	8.0	90	1.1	5	65.7	0	0	102	0	0	0	0	0	0	0
First Creek	8	0	0	8.0	60	1.5	4	56.0	0	0	0	0	0	0	0	0	0	0
Little Creek	8	0	0	10.0	68	.6	3	154.4	0	0	504	0	0	0	0	0	0	0
Total or average	69	2	2.9	8.5	77	.9	5	636.9	.6	.1	1,120	3	.3	12	1.3	.2	1	.1

Aho and others (1979) found that incidence of infection and volumes of wood decayed were significantly greater when grand fir tops were killed by tussock moth defoliation and were also attacked by bark beetles and wood borers than when tops were killed by defoliation only. In this study, only five top-kills (7 percent) of true fir had also been attacked by beetles. The two dead tops infected by decay fungi had been attacked by bark beetles and wood borers. These results agree with those found by Basham (1980) in his study of deterioration of balsam fir (*Abies balsamea* (L.) Mill.) killed by spruce budworm. All trees in stands heavily attacked by bark beetles had advanced sap rot 1 to 2 years after death, but no advanced sap rot was found in dead balsam firs in stands with little beetle activity.

Twelve infections by decay fungi were associated with injuries, mainly trunk wounds, other than top damage (table 3). As with the Douglas-fir sample, little decay was caused by these infections.

The only fungi capable of causing decay were isolated from the three dead tops that had columns of associated rot. Both decay columns in true fir trees were caused by *Pholiota limonella* (Pk.) Sacc. *Fomitopsis cajanderi* (Karst.) Kitl. et Pouz. was responsible for the decay associated with the only infected Douglas-fir dead top. Most microorganisms isolated were fast-growing, nonhymenomycetous fungi. Bacteria were also frequently isolated.

Proportion of "Dead" Tops Actually Dead

Entomologists have noticed that some portions of tops that appeared dead have put on new foliage in succeeding years.[1] In this study, 27 percent of apparently dead Douglas-fir tops and a quarter of true fir top-kills were not completely dead. The average length of apparently dead Douglas-fir tops was 1.6 feet. Average length of the tops actually dead was 1.3 feet. The difference between the apparent top length and the actual dead length for true firs was 0.5 foot (1.9 vs. 1.4 feet). In most cases, the difference between the length of apparent and actual dead tops was only a few tenths of a foot; however, in some circumstances the difference was substantial. For instance, a dead Douglas-fir top appeared to be 8.3 feet long, but the cambium and branch tips were dead only 3.8 feet back from the tip. Similar observations were made in the true fir sample.

[1] Personal communication from Robert D. Harvey, Jr., USDA Forest Service, Pacific Northwest Region, Portland, Oregon.

Height Losses

When only the last year or two of the tops of Douglas-firs or true firs are killed by western spruce budworm defoliation, little height growth is lost because a lateral branch quickly assumes dominance and forms a new treetop. When defoliation causes a treetop to die back several years, height growth loss is more severe. Average height losses of severely top-killed trees (the last 3 or more years of growth was killed) were 4.3 feet for Douglas-fir and 4.4 feet for true firs. Regrowth of tops by lateral branches was 0.9 foot for Douglas-fir and 1.1 feet for the true firs. Laterals lower in the tree are less likely to express dominance or are slower to, perhaps because they are less vigorous than the younger laterals near the original top or because the trees with extensive top-kill were so badly damaged by defoliation that the laterals could not respond.

Williams (1967) has shown that there is a differential effect on severity of top-kill damage to host tree species defoliated by WSBW. True firs (grand and subalpine firs) are apparently more severely top-killed than are Douglas-fir by budworm defoliation. Such a difference was not observed in this study, possibly because of a lack of a secondary attack by bark beetles on species of either genus.

Conclusions

Decay losses associated with top-kill of Douglas-fir and true firs caused by western spruce budworm defoliation were very low in the Wenatchee and Okanogan National Forests up to 10 years after the infestation subsided. Incidence of infection and extent of decay have been limited by the small basal diameters of tops, the recency of damage, and the lack of secondary attack by beetles. There did not appear to be a differential effect of damage on host species as reported by others.

If conditions in most stands severely defoliated by the WSBW in the Wenatchee and Okanogan National Forests are similar to those found in the 14 stands sampled, decay losses associated with dead tops should be very low. If deductions for decay are to be made, they should be made for dead tops with large basal diameters (>2.0 inches) and for secondary attacks by beetles. Even under these conditions, decay losses would be low because the tops have not been dead long enough for extensive columns of rot to develop.

Acknowledgment

Thanks are extended to Bill Andrews and Dave Renner for their help in carrying out the field and laboratory phases of the study; Bob Harvey's help in planning the study is also appreciated.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 cubic foot = 0.028 32 cubic meter
1 acre = 0.4047 hectare

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Aho, Paul E. Losses associated with Douglas-fir and true fir tops killed bv western spruce budworm in eastern Washington. Res. Pap PNW-318. Portland, OR: U.S. Department of Agriculture, Forest Service. Pacific Northwest Forest and Range Experiment Station **1984.** 8 p.

A sample of 133 Douglas-firs (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and 69 true firs (*Abies* spp.) with dead tops caused by defoliation by the western spruce budworm (*Choristoneura occidentalis* Freeman) were felled, dissected, and examined for height loss and incidence and extent of decay. Height loss was negligible for trees with only the last year or two of their tops killed by defoliation because lateral branches quickly formed new tops. Height losses of trees severely damaged by top-kill averaged 4.3 feet for Douglas-fir and 4.4 feet for true firs, but some trees had new tops with an average length of 0.9 foot for the Douglas-firs and 1.1 feet for the true firs. Only three trees were infected by decay fungi, and associated loss of volume was negligible.

Keywords: Insect damage (-forest, increment (height), crown damage, decay (wood), heartwood rot, western spruce budworm, Douglas-fir, *Pseudotsuga menziesii,* true fir, *Abies* spp., Washington (eastern), eastern Washington.

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The Value of Roaded, Multiple-Use Areas as Recreation Sites in Three National Forests of the Pacific Northwest

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Harriet H. Christensen, and John C. Hendee

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Abstract

Clark, Roger N.; Koch, Russell W.; Hogans, Mack L.; Christensen, Harriet H.; Hendee, John C. The value of roaded, multiple-use areas as recreation sites in three National Forests of the Pacific Northwest. Res Pap. PNW-319. Portland, OR: U.S Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 40 p.

Dispersed recreation along forest roads in generally undeveloped areas is increasing rapidly in the West. To effectively manage this use and integrate it with other forest activities requires information about the preferences, expectations, and opinions of forest visitors and their patterns of recreation use. Results of a 3-year study of campers and day users in three roaded forest areas of Washington and Oregon suggest this type of area provides opportunities that are very different from those in developed campgrounds and primitive backcountry. Visitors to roaded, forested areas like the generally unpaved road access, the low level of use, and the freedom to alter campsites to suit their objectives. Although this type of recreation is found in conjunction with resource management activities, such as logging and livestock grazing, recreationists do have favorite sites they return to year after year. Such sites may, therefore, warrant some protection. Future management programs must consider the value recreationists place on these sites and area attractions and the noneconomic as well as economic costs associated with altering these settings.

Keywords: Dispersed recreation, recreation (dispersed), recreation use, roads (forest), logging effects, recreation management, multiple use –) recreation, recreationists.

Summary

Recreationists using selected roaded areas in three National Forests in the Pacific Northwest were surveyed to determine their patterns of use, preferences, and concerns regarding management practices in the areas. Logging has occurred within each area, and much of the recreation use has resulted from effects of timber management; for example, roads and clearcuttings. Few recreation facilities exist in the roaded areas.

Visitors sampled prefer roaded, forested areas over Wilderness Areas and backcountry or developed campgrounds. Lack of more desirable areas was not a reason they visited these locations; reasons included privacy, lack of development, freedom, and the fact that camping in such areas is "their style."

Users generally did not desire additional facilities and conveniences in the areas. Some were concerned that "improvements" such as garbage cans, toilets, or water supplies might attract other people, thereby increasing the competition for available sites.

Users indicated that opening new areas for such recreation is a good reason for building new roads, but they do not want more roads in the areas they already visit. Road access is important to them, but they generally do not want roads to be paved.

Many of the users believe other resource management practices can be compatible with recreation. Most of the users studied in these areas depends on logging and associated roads. Unlike Wilderness Area users, visitors to roaded areas do not object to logging (or grazing in one of the areas where it is common) per se. Although the size of clearcutting and its location relative to roads and campsites are important, visitors to the study areas do not reject roads, logging, and clearcutting as might Wilderness Area users.

Introduction

The location, design, and maintenance of roads are key elements in providing diverse opportunities. Locating appropriately designed roads in desirable locations will allow users to create campsites to accommodate their needs. Ignoring these elements will eliminate many options for the public.

It may be necessary to destroy some recreation sites when entering an area for additional timber harvest, but the forest manager should be aware of the effect such a decision has on the forest visitor. Where possible, prime sites should be buffered from roads and clearcuttings to maintain qualities important to users.

There is great potential for increasing opportunities for dispersed recreation in roaded forests. The sensitivity of managers and their creativity in finding ways to accommodate forest users will maximize such options.

The invention of the automobile in the early 1900's and its subsequent improvement provided many Americans access to previously hard-to-reach forest lands. Recreationists on pleasure excursions into the forests often pulled off the road at an appealing location and set up impromptu campsites. They built stone fire rings to keep warm and to cook meals, and they used water from nearby streams and lakes (Meinecke 1937).

Foresters responsible for managing that land often reacted negatively to the dispersed, recreational use at unofficial sites; they felt that campfires would result in widespread forest destruction. The lack of sanitary facilities was perceived as a menance to public health (Stahl 1921) (fig. 1). Developed recreation sites with numerous convenience facilities originally emerged in this country as an attempt to dissuade dispersed recreation (Clark and Stankey 1979a, Ellison 1942).

A recent study indicated that managers felt benefits of dispersed, motorized recreation may be overshadowed by the costs (Downing and Moutsinas 1978, Downing and Clark 1979). Yet the growth in recreational activities associated with the use of motorized vehicles has been impressive, even with recent shortages of gasoline and increases in its price (fig. 2).

Dispersed rcreation in generally undeveloped areas is one of the fastest growing forms of outdoor recreation in the United States (Lloyd and Fisher 1972). This type of recreation accounted for nearly two-thirds of all recreational use in National Forests in fiscal year 1982 with much of this use occurring on or along the more than 245,000 miles of National Forest roads and trails (fig. 3).

Figure 1.—Improved automobiles of the early 1900's enabled Americans to explore forest lands. Developed recreation sites first emerged in an attempt to discourage this dispersed recreation.

Figure 2.—In spite of increased gasoline prices, recreational activities using motorized vehicles continue to grow in popularity.

Figure 3.—Dispersed recreation on roaded forest lands is a popular form of outdoor recreation.

Managers and planners of public agencies and some private corporation now recognize the importance and appeal of dispersed, motorized recreation and are seeking effective ways to better integrate it with other forest uses. As one example, the importance of dispersed recreation to future management of the National Forests was addressed in the Resources Planning Act of 1974. The recommended policy calls for an increase in the supply of outdoor recreation opportunities and services through programs emphasizing dispersed recreation.

Compared to other recreational opportunities available to the public (for example, Wilderness Areas and developed campgrounds), little information has been generated concerning dispersed, motorized recreation. In 1975, in response to management concerns about how such recreation should be managed, the Wildland Recreation Research Project of the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, began studying this type of recreation along roads in three National Forests in the Pacific Northwest. For the study, dispersed, motorized recreation was defined as any recreation that is generally dispersed in nature and that use of motorized vehicles is appropriate for access and for certain types of activities. Initially, inventories were completed to provide detailed geographical, physical, and social characteristics of dispersed recreation sites. Most of these sites were established by users (Hendee and others 1976a). In addition, the nature and amount of dispersed day and overnight use was determined (Hendee and others 1976b): (1) the majority of dispersed recreation occurs at low elevations in user-created campsites near water, (2) dispersed recreation use peaks on weekends and holidays (3) day use is far more prevalent than overnight use, (4) the majority of dispersed recreationists live less than 150 miles from the sites and tend to come from metropolitan areas, (5) most users have been to the area before, (6) weather plays an important role in participation patterns, and (7) dispersed recreationists participate in a wide array of activities including camping, hiking, fishing, hunting, motorbiking, and driving for pleasure.

The purpose of this paper is to describe results of a survey of dispersed recreationists along forest roads in selected areas in National Forests of the Pacific Northwest. The study was an attempt to determine the characteristics of dispersed campers and day users, and to identify their patterns of use, preferences, and attitudes. Objectives behind specific survey questions were to determine individual patterns of dispersed recreation use; to identify the preferences, satisfactions, and activities associated with dispersed, motorized recreation; and to determine how participants behave and feel in regard to resource management issues that could affect policies directed at dispersed, motorized recreation.

Study Areas

The survey was conducted in three study areas on National Forest lands in the Pacific Northwest. The areas were chosen because they reflected a range of dispersed, roaded recreation environments in the Pacific Northwest. Ten selection criteria were used to insure that the study areas chosen would include the conditions of greatest concern to National Forest management.[1] A total of 28 candidate areas were submitted for possible study. The Greenwater, Taneum-Manastash, and upper Clackamas areas of the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests most fully met the selection criteria (fig. 4).

Figure 4.—Location of the Greenwater, Taneum-Manastash, and upper Clackamas study areas.

[1] These criteria were: interest by local managers in participating, intermingled public and private ownership, current or imminent road closures, spectrum of nearby recreation opportunities, proximity to a large metropolitan area, off-road vehicle use, forest conditions typical of large categories of National Forest land, different timber harvest methods used, fairly close transportation system to facilitate measuring traffic, and a minimum of unusual recreation attractions.

Greenwater Study Area

The Greenwater drainage is located 60 miles southeast of Seattle in the White River Ranger District of the Mount Baker-Snoqualmie National Forest in western Washington. The main Greenwater road leaves State Highway 12—a scenic cross-mountain route to eastern Washington—less than 20 miles from a major entrance to Mount Rainier National Park. The main road ranges in elevation from 1,900-2,700 feet along the Greenwater River. There are no developed campgrounds or recreation facilities in the drainage, but there are private, State, and USDA Forest Service campgrounds within 20 miles. In much of the area, alternate sections of land are owned by a private timber company. The 78-mile road system was constructed primarily for timber harvesting and is maintained under share-cost road maintenance agreements between the Forest Service and private timber companies. There are numerous clearcuts throughout the drainage, logging is in progress at several locations, and additional timber harvest and road construction are planned. Previous research identified over 117 user-defined recreation sites along the 78 miles of road in 1975 (fig. 5A).

Taneum-Manastash Study Area

The Taneum-Manastash area is in the Cle Elum Ranger District of the Wenatchee National Forest in eastern Washington. The study area is a few miles south of Interstate 90, approximately a 2-hour drive from Seattle. Adjacent and intermingled lands are owned by the State of Washington and a private timber company. In 1976, the area include 47 miles of mainline logging road and 44 miles of dirt, spur roads. The study area covers approximately 70,000 acres and ranges in elevation from 2,000 feet along Taneum Creek to over 6,300 feet at the top of Quartz Mountain. There are several trailheads leading to adjacent backcountry and four nearby lakes. In the fall, the area is heavily used by deer and elk hunters. The area includes one moderately developed campground with 21 sites and 4 other locations with 2-5 minimally developed sites. The area has clearcut and selective harvest logging units and a long history of sheep and cattle grazing. Several cattle grazing allotments are currently active. Previous research identified 291 user-established recreation sites along 95 miles of road in 1975 (fig. 5B).

Upper Clackamas Study Area

The upper Clackamas study area is in the Clackamas and Estacada Ranger Districts of the Mount Hood National Forest in western Oregon. The area lies adjacent to the main Clackamas River road, a two-lane forest highway that serves as a scenic forest loop highway from Portland through the Mount Hood and Willamette National Forests to the town of Detroit in western Oregon. The Clackamas drainage has hundreds of miles of forest roads built primarily for timber harvest. The popular Bagby and Austin Hot Springs are near the study area. Three minimally developed campsites (no toilets), three highly developed Forest Service campgrounds, and one privately developed picnic site owned by Portland General Electric Company are within the study area. Because the upper Clackamas is such a large area, only four of its roads were selected for study. They include: 21 miles of State Highway 224 from Ripplebrook Ranger Station to Squirrel Creek, 80 miles of the Fish Creek road system, 70 miles of the Oak Grove-Shellrock Creek road system, and 30 miles of Squirrel Creek road system. A total of 214 user-established recreation sites were identified in these areas in 1975 (fig. 5C).

Figure 5A— The Greenwater study area, located 60 miles southeast of Seattle in the Mount Baker-Snoqualmie National Forest, has no developed campgrounds or facilities; active logging occurs at many locations.

Figure 5B.—The Taneum-Manastash study area in the Wenatchee National Forest in eastern Washington has a long history of logging and livestock grazing; it is a favorite area for deer and elk hunting.

Figure 5C.—The upper Clackamas study area, located in the Mount Hood National Forest in northwest Oregon, is a large area with hundreds of miles of forest roads and several minimally to highly developed campsites.

Methods

Characteristics of the Recreation Sites

Tables 1 and 2 summarize the major characteristics of the dispersed sites located in the three study areas; some of the data will be referred to elsewhere in this report. The characteristics are discussed in detail in Hendee and others (1976a).

To satisfy the objectives of the study, we developed a questionnaire and a brief interview for the users. The interview, conducted prior to giving questionnaires to the users, was, in part, an observation form and sought information related to the purpose of their trip, composition of their group, and whether their trip was for the day or overnight. The 9-page questionnaire consisted of 88 questions and took about a half hour to complete. The survey was pretested for clarity and for its ability to elicit the type of responses we intended.

Table 1—Miles of road and number of dispersed recreation sites in the three study areas, by type of road

Study area and unit	River bottom roads	Midslope roads	Ridgetop and side roads	Total or average
Greenwater:				
Miles of road	9	5	9	23
Number of recreation sites	64	23	30	117
Average number of sites per mile	7.1	4.6	3.3	5.1
Taneum-Manastash:				
Miles of road	10	10	75	95
Number of recreation sites	96	57	138	291
Average number of sites per mile	9.6	5.7	1.8	3.1
Upper Clackamas:				
Miles of road	48	32	121	201
Number of recreation sites	179	25	10	214
Average number of sites per mile	3.7	.8	.1	1.1
All study areas:				
Miles of road	67	47	205	319
Number of recreation sites	340	105	177	622
Average number of sites per mile	5.1	2.2	1.9	1.9

Sampling

In earlier research in the same areas (Hendee and others 1976b), apparent differences emerged between campers and day users. Day users appeared to be oriented toward specific activities, such as motorcycling or fishing, and were scattered over large portions of the study area (fig. 6A). Campers, however, seemed to spend much of their time in camp doing chores and just relaxing; consequently they spent less time participating in specific recreation activities (fig. 6B). There were logistical problems sampling highly mobile day users, yet it was important to have a representative sample of both user types. Overnight camper and day users were therefore treated as distinct populations and were sampled separately. Although the two samples reflected the responses of each user group, they also created constraints in analyzing the combined data. The constraints will be discussed later.

The sampling period extended from July 1 to November 16, 1976, and was separated into distinct summer (July 1-September 5) and fall (September 5-November 16) seasons. During the summer season, questionnaires were distributed Thursday through Monday in the Taneum-Manastash area but were handed out only on Saturdays and Sundays in the Greenwater and upper Clackamas areas because of their infrequent use after Labor Day.

Table 2—Characteristics of dispersed recreation sites [1/]

Characteristics	Greenwater		Taneum-Manastash		Upper Clackamas		Total	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
1. Site near roads:								
Main road	49	(42)	79	(27)	123	(58)	251	(40)
Spur road	65	(55)	153	(52)	25	(12)	243	(39)
Informal road	3	(3)	41	(14)	62	(29)	106	(17)
4-wheel drive road	--	--	20	(7)	3	(1)	23	(4)
2. Site capacity:								
No vehicles, tent only	2	(2)	10	(3)	14	(7)	26	(4)
1 vehicle	12	(10)	8	(3)	58	(27)	78	(13)
2 vehicles	37	(32)	16	(6)	101	(47)	154	(25)
3 vehicles	20	(17)	47	(16)	17	(8)	84	(13)
4 vehicles or more	46	(39)	212	(72)	24	(11)	282	(45)
3. Visual isolation (no. of other sites in view):								
0	41	(35)	128	(44)	96	(46)	265	(43)
1-3	66	(56)	137	(47)	88	(42)	291	(47)
4-5	9	(8)	23	(8)	18	(9)	50	(8)
6 or more	1	(1)	3	(1)	7	(3)	11	(2)
4. Dispersal (no. of sites within 1/2 mile):								
0	4	(4)	7	(2)	24	(11)	35	(6)
1-3	43	(38)	108	(37)	26	(12)	177	(29)
4-5	14	(13)	44	(15)	42	(20)	100	(16)
6 or more	51	(45)	132	(46)	120	(57)	303	(49)
5. Availability of firewood:								
Abundant	12	(10)	27	(9)	52	(24)	91	(15)
Available	104	(89)	220	(75)	116	(55)	440	(70)
Scarce	0	(0)	45	(15)	40	(19)	85	(14)
None	1	--	1	--	5	(2)	7	(1)
6. Availability of water:								
Adjacent to site	53	(45)	111	(38)	149	(70)	313	(50)
Available nearby	22	(19)	170	(58)	18	(8)	210	(34)
No water available	42	(36)	12	(4)	47	(22)	101	(16)
7. Toilets:								
Accessible to site	0	(0)	76	(35)	6	(3)	82	(13)
Not accessible to site	117	(100)	217	(65)	208	(97)	542	(87)
8. Facilities at site:								
None	155	(98)	207	(75)	211	(98)	533	(89)
Sign	2	(2)	49	(18)	0	(0)	51	(9)
Garbage can	0	(0)	2	--	2	--	4	--
Table	0	(0)	11	(4)	1	--	12	(2)
9. Estimated environmental impact at site:								
Extreme	2	(2)	0	(0)	8	(4)	10	(2)
Heavy	11	(9)	47	(16)	13	(6)	71	(11)
Moderate	36	(31)	146	(50)	76	(35)	258	(41)
Light	68	(58)	100	(34)	117	(55)	285	(46)
10. Estimated frequency of site use:								
Heavy	7	(6)	0	(0)	10	(5)	17	(3)
Frequent	26	(22)	35	(12)	14	(6)	75	(12)
Moderate	18	(15)	62	(21)	40	(19)	120	(19)
Slight	16	(14)	99	(34)	53	(25)	168	(27)
Infrequent	50	(43)	97	(33)	96	(45)	243	(39)
11. Recorded frequency of site use (1975):								
Heavy (25-56 nights)	2	(2)	13	(4)	9	(4)	24	(4)
Frequent (19-24 nights)	1	--	10	(3)	9	(4)	20	(3)
Moderate (13-18) nights)	7	(6)	22	(8)	23	(11)	52	(8)
Slight (7-12 nights)	22	(19)	42	(14)	40	(19)	104	(17)
Infrequent (1-6 nights)	24	(21)	88	(30)	73	(34)	185	(29)
Unused	61	(52)	121	(41)	60	(28)	242	(39)

1/ Based on a 1975 Code-A-Site inventory. Approximate number of dispersed recreation sites inventoried: Greenwater 117, Taneum-Manastash 293, and upper Clackamas 214. Percentage in category 8 do not total 100 because the characteristics are not mutually exclusive.

Source: Hendee and others (1976a).

Figure 6A.—Day users engage in specific activities, such as motorbiking or fishing, and are generally scattered over a wide area.

Figure 6B.—Campers spend more time in camp doing chores or just relaxing.

Selection of Sampled Users

Beginning July 1, field assistants distributed questionnaires to campers at their campsites in each of the three study areas. The next day, they distributed the questionnaires to day users as they entered the areas. On the third day, campers were sampled. This alternate-day pattern, followed for the remainder of the sampling period, was designed to nullify any biases that might have resulted from seasonal factors such as rainfall and snowpack.

Day users.—A day-use party was defined as one person or a group traveling together into the area for a stay that did not involve overnight camping. Questionnaires were distributed to day users every other sampling day by stopping every other vehicle at fire prevention stations at the entrance to the study areas. Hours of distribution alternated between morning (8 a.m. to 1 p.m.) and afternoon (1 p.m. to 6 p.m.) to cover the primary period of entry. Heavy traffic along the road sometive made it impossible for the field assistants to interview potential study participants; some parties were then waved on to reduce traffic congestion. The number waved on did not exceed 20 percent for any of the areas. It was presumed that because day users arrived at the study area in random order, the failure to contact these users would not have a significant effect upon the outcome of the survey. After a selected day-use party had been stopped, the adult driver and passenger (where available) were asked if they would participate in the survey. Women, often not represented in recreation surveys, were purposely sought out. When parties agreed to participate, the interview was conducted and the participants were instructed about how to complete and return the questionnaire. Less than 1 percent of the day users contacted elected not to participate in the interview (fig. 7).

Figure 7.—To sample day users, alternate vehicles were stopped every other day; occupants were interviewed then handed a questionnaire.

Campers.—A camping party was defined as all people camping together at a site. Sampling campers in the study areas presented a problem because the areas were too large to be covered by the number of field assistants employed. To overcome the problem, we constructed a frequency-of-use index based on data collected with the Code-A-Site system (Hendee and others 1976a) (see table 2). The study areas were then divided into functionally equivalent zones, enabling field assistants to select their sample from 100 percent of the camping parties in the zone. Had the Greenwater study area not been divided into zones, for example, only about half the 117 campsites could have been sampled. By dividing the area into two zones, however, any party entering either zone to camp overnight had a 50-percent chance of being sampled.

The zones in each of the study areas were sampled sequentially, beginning with a random start, on the alternate days. On each of these days, field assistants attempted to contact all camping parties present in the selected sampling zones. Campers arriving after the field assistants had visited the campsites on their patrol route were included in the survey only if the campers remained in the area long enough to be included in the next round of sampling. The field assistants varied their patrol routes by starting at opposite ends of the sampling zone each time they distributed questionnaires to avoid any bias resulting from a constant patrol route. The core sampling times were from 8 to 10 a.m. and from 4 to 8 p.m. It was not practical to sample during midday because many campers left their sites to participate in offsite activities (fig. 8).

When calling on an occupied campsite, the uniformed field assistants explained the nature and purpose of the study and asked if the head of the party (selected by the party) and a female or male companion (if both were present) would like to participate. If they agreed, the field assistant conducted the interview, explained how to complete and return the questionnaire, and thanked the party for their cooperation. Less than 1 percent of the camping parties declined to participate.

Figure 8.—Field assistants visited campsites on alternate days to distribute questionnaires to overnight campers in selected sampling zones.

User Response to the Survey

Methods of returning questionnaire.—Potential respondents were instructed to return the questionnaire in one of three ways: (1) complete it while in the study area and return it at the fire prevention check station when they left, or (2) give it to the field assistant at a mutually agreed upon time, and (3) complete the questionnaire after leaving the site and return it in a prepaid envelope included with each questionnaire. Although the first two methods were encouraged to help increase the response rate, the majority of questionnaires were returned by the third method.

Follow up procedures.—During the interview the head of a party was asked to write his or her name and address on a post card; the card was then kept by the field assistant. At the end of every week in the field, each post card was given to clerical staff; the questionnaire number and the name and address of the potential respondent was then sequentially entered on lists by study area. If we did not receive the questionnaire after 1 week from the date of interview, we mailed the post card to the potential respondent. The post card contained a printed reminder to mail a completed questionnaire. If we had no response by the end of the second week, we mailed an identical questionnaire to the potential respondent with a personalized letter from the field assistant. At the end of the third week we mailed a final post card reminder. If we still did not receive a questionnaire, we classified the party as a nonrespondent and made no further effort to contact the individual.

Response rate.—Of the 3,435 questionnaires that were distributed to day users and campers in the three areas, 2,180 (63 percent) were returned (table 3). The response rate was slightly higher for campers (68 percent) than for day users (60 percent) and differed somewhat among the areas (Greenwater 60 percent, Taneum-Manastash 75 percent upper Clackamas 59 percent). The discrepancy in response rate between areas was related to workloads of the field assistants stemming from conditions within study areas. For example, the Taneum-Manastash (where the highest response rates were obtained) had relatively few visitors and permitted field

Table 3—Number of respondents and response rate for questionnaires distributed, by study area 1/

Study area	Campers	Day users	Total or average
Greenwater:			
Number of respondents	284	375	659
Response rate (percent)	(63)	(58)	(60)
Taneum-Manastash:			
Number of respondents	419	268	687
Response rate (percent)	(79)	(70)	(75)
Upper Clackamas:			
Number of respondents	195	639	834
Response rate (percent)	(60)	(58)	(59)
All areas:			
Number of respondents	898	1,282	2,180
Response rate (percent)	(68)	(60)	(63)
Statistical summary	χ^2=221.4; $p \leq 0.001$; not significant		

assistants to spend more time conducting the interview and revisiting campsites to pick up questionnaires. Conversely the large amount of weekend traffic along State Highway 224 in the upper Clackamas area tended to result in "rushed" interviews at times.

Comparison of respondents and nonrespondents.—Because all potential respondents were briefly interviewed before being given questionnaires, we have some information about those who did not respond. In the case of day users, respondents were more likely to have visited the study area previously, and were slightly more likely to have been classified as senior citizens. No statistically significant differences between respondents and nonrespondents were found for size of their city of residence, weekday versus weekend use, and size of their party.

For campers, respondents were more likely to have been contacted on a weekday, to be senior citizens, to have stayed in the study area a longer period of time (thereby increasing followup contacts), and to have camped in a recreational vehicle rather than a tent.

Responding campers were also more likely to have been with a smaller-than-average group (less than 6 people). No statistically significant relationship was observed between the size of their city of residence or their tendency to respond.

Most of the statistically significant differences were small and none of the differences observed is believed to have any major substantive importance for the findings described in this paper.

This section summarizes the responses from 2,180 persons in the three study areas. Discussion of the results covers background characteristic, patterns of recreation, preferences for recreation setting, perceptions of management problems, and attitudes about specific forest management activities.

As indicated previously, day users and campers were sampled separately. Although the data from each sample reflect the views of that type of user, the samples cannot be combined without knowing the relative proportion of day users and campers in dispersed recreation areas. To avoid this complexity, the samples have not been combined in the following analyses, and responses are reported separately for day users and campers on all issues. To facilitate comparisons, all tables present the data as percents; this effectively standardizes the two samples, which were of unequal size (Reynolds 1977). The reported statistics however, have been calculated from the actual values of each cell in the table.

Statistical tests (Chi-square, difference-of-proportions) were performed to determine the difference in responses between the day users and campers. Where no significant differences were apparent, it can be assumed that these data reflect the general view of all dispersed area users. Where statistical differences were significant, a measure of association (gamma) was used to indicate the degree to which campers and day users differed in opinion. For issues in which this difference is large (as measured by gamma), it will be important to consider the views of each type of user when attempting to reflect dispersed area recreationists in general.

Background Characteristics of the Respondents

A brief synopsis of the background characteristics of respondents is presented to help the reader interpret the data presented in this paper. A few comparisons are made where data are a available between the respondents in this study and those in other recreation studies.

Residence.—The majority of visitors to the three study areas drove about 2 hours or less to reach their destinations, coming from nearby metropolitan areas—Seattle and vicinity for the Greenwater and Tadneum-Manastash areas, and Portland and vicinity for the upper Clackamas area. In this regard, dispersed road-oriented users are probably similar to other recreationists.

Age.—Respondents averaged 38 years old for both campers and day users. No important differences were noted between areas. These ages are not indicative, however, of the users in the areas because the sampling strategy excluded persons younger than 18 years old and favored heads of parties who might be expected to be older. These data compare reasonably well with findings in several Wilderness Areas during the 1970's (Hendee and others 1978). Wilderness users tended to be slightly younger than the users of dispersed, roaded areas, but all age groups are well represented in both types of areas.

Education.—Respondents in this study had received an average of 13 years education, although 50 percent more day users reported having 13-16 years of schooling than did campers. A smaller percentage of users in our study had 5 years or more of college than did Wilderness Area users in another study (Hendee and others 1978). Day users in our study more closely resembled Wilderness users in length of education than did the campers.

Income.—Average reported family income was about $16,000 for both campers and day users, and about 80 percent of the sample reported total annual family incomes of greater than $12,000. This average is somewhat understated because the questionnaire did not allow for persons earning more than $24,000 to specify their exact income. As a comparison, average family income reported by the Bureau of the Census for this period was $13,850 for Oregon and $14,960 for Washington. So our sample appears somewhat more affluent than would be a sample of the general public, a finding similar to studies of other recreationists including Wilderness Area users.

Sex.—One intention of the sample design was to obtain about an equal number of males and females in the survey. For campers this goal was closely met (53 percent males), but for day users a much higher proportion of males were included in the survey (65 percent). The difference may have resulted from the higher proportion of men encountered as day users during both summer and fall seasons in these areas.

Occupation.—Professional/technical, craftsmen, kindred workers, and housewives accounted for almost half the respondents. An additional quarter of the sample were in the managerial/administrative, clerical, and retired categories, with the others widely spread among a variety of other occupations. More day users than campers were professional/technical workers, similar to Wilderness Area users in this regard (Hendee and others 1978). Few farm workers visited these recreation areas even though the Greenwater and Taneum-Manastash areas are located near agricultural regions.

With respect to these background characteristics, the sample is diverse in composition. As Shafer (1969) indicates, there are no suitable stereotypes or mythical averages. Day users are similar to campers in some ways, yet different in others. Several of the differences noted seem to indicate that, as far as background variables are concerned, day users are more closely related to Wilderness Area users than are campers in the study. This issue will be discussed more thoroughly later.

Patterns of Dispersed Recreation Along Forest Roads

Respondents' history of use in the area.—Results indicate that most visitors had been coming to this area for many years; the average user first visited the study area more than 7 years before the interview. The Taneum-Manastash users' average of more than 9 years was significantly higher than for the other areas, perhaps because relatively good hunting in this area encourages some hunters to return year after year.

Respondents had also visited the area on many occasions (table 4). Nearly half had been to the area more than 11 times in the past. The upper Clackamas appeared to be an exception in that more visitors had not been in the area before; a State highway goes through the area, which may result in more "pass-through" tourists who are unlikely to return in the future. The Taneum-Manastash and Greenwater areas have a more closed transportaion system, limiting the pass-through users.

Table 4—Percentage of users having previously visited the study area where contacted

Number of visits	Campers	Day users
None	12	13
1	8	8
2-4	15	11
5-10	19	12
11 or more	46	56
Total	100	100
Statistical summary	$\chi^2=36.06$; $p \leq 0.001$; $\gamma=0.11$	

1/ Based on the number of users who responded: campers 888; day users 1,239.

How they learned about the areas.—Information about recreation opportunities in dispersed, roaded areas is not as readily available as it is for developed campgrounds or Wilderness Areas, for which agency maps, directories and popular publications are common. With this lack of information through agencies, how do people learn about these areas?

Table 5 incidates that informal personal contacts, most often family and friends, are the most important source of information about opportunities for recreation in dispersed, roaded areas. Fazio (1979) found similar results in a study of Wilderness Ares users, even though more information is available about those opportunities.

The large number of people who found the areas while exploring was significant. Driving the roads in areas like the Taneum-Manastash, upper Clackamas, and Greenwater is a growing recreation activity. In these areas alone, more than 300 miles of roads of various standards are open for public travel.

Some forest managers have begun to prepare material on dispersed, roaded areas for distribution to the public. How this will affect use of areas like those studied cannot be determined yet. If the traditional nature of use and predominant, secondary sources of information holds true, however, the information may not have any direct effect. But those who do use such information may pass it on to others with a resulting multiplier effect. This could be particularly important when accurate information needs to be communicated. As Potter and others (1973) pointed out in a study of pheasant hunters, informal communication may result in erroneous or misleading messages being passed around.

Proportion of times users camp.—Nearly 90 percent of the respondents identified as campers in the survey usually or always camp when visiting dispersed, roaded areas (table 6). Only slightly more than 30 percent of the day users usually or always camp in such areas. But most day users camp at least sometimes—only 15 percent said they never camp when they go to such areas. Whether the difference in camping patterns between these two groups is reflected in their attitudes and preferences is explored later in this paper.

Favorite sites.—Not only did most recreationists return frequently to the same area, but they often return to favorite spots (85 percent of campers and 74 percent of day users) (table 7). This was true in all three areas for both campers and day users, although campers were more likely to return to favorite locations than were day users.

Favorite locations may have certain characteristics that have made them attractive. Consequently, if planning and management is to facilitate dispersed recreation in areas like those in this study, it is important to identify which types of sites have particular appeal for recreationists. Information such as that summarized in table 2 and discussed in later sections of this paper can aid in making decisions about future management of sites used by recreationists (fig. 9).

Style of camping.—Dispersed recreation areas are generally characterized by their lack of facilities (table 2). In our three study areas, for example, most camping parties compensate for the lack of facilities by bringing their own equipment (fig. 10). Table 8 shows that many bring recreation vehicles (RV's), with pickup campers and trailers being the most popular. These RV's provide users with many home-like comforts. About a third of the campers were staying in trailers, another third in pickup campers, a fourth in tents, and the remainder were in motor homes, vans, or out in the open. The high use of many types of RV's represents a large investment for users and is a measure of their commitment to this type of recreation. What effect increasing gasoline costs will have on the use of RV equipment in these areas cannot be ascertained, although trends towards smaller rigs and more frequent trips to closer areas have been noted.

Table 5—How users learned about the study area where they were contacted 1/

(In percent)

Source of information	Campers	Day users
Friends or acquaintances	46	40
While exploring the area	32	34
Family	21	23
While working in the area	6	6
Publication, map, or brochure	3	6
Organization or club	4	3
Newspaper, magazine, or mass media	2/	2
Land management agency representative or official	2/	2
Total 3/	112	116
Statistical summary	χ^2=48.00, p < 0.001; not significant	

1/ Based on the number of users who responded: campers 879; day users 1,218.
2/ Less than 1 percent.
3/ Totals equal more than 100-percent because some respondents gave more than one source of information.

Table 6—Percentage of occasions users camp when visiting dispersed, roaded, recreation areas 1/

Frequency	Campers	Day users
Never camp	2/	16
Sometimes camp	9	37
Camp half the time	4	13
Usually camp	39	24
Always camp	48	9
Total	100	100
Statistical summary	χ^2=679.00; p < 0.001; =-0.77	

1/ Based on the number of users who responded: campers 877; day users 1,222.
2/ Less than 1 percent.

Table 7—Percentage of users who have and do not have favorite spots to which they return 1/

Favorite spot	Campers	Day users
Yes	85	74
No	15	26
Total	100	100
Statistical summary	χ^2=33.38; p < 0.001; =0.32	

1/ Based on the number of users who responded: campers 847; day users 1,160.

Figure 9.—Both day users and campers returned frequently to the same recreation area and often to the same spot. Identification of these popular sites will facilitate management of dispersed recreation.

Figure 10.—Dispersed recreation areas generally have no facilities, so campers bring their own equipment such as trailers, campers, or vans.

Table 8—Camping style of users 1/

Camping style	Percent of campers
Trailer	22
Pickup camper	33
Tent	21
Motor home	5
In the open	4
Van	5
Total	100

1/ Based on the responses of 819 campers.

Number of vehicles at sites.—Motor vehicles play a dual role in dispersed roaded areas. They serve as a means to get to preferred sites, and they also are a necessasry part of many recreation activities. About half of the camping parties brought two or more vehicles to the study areas. Overnight users often drove passenger sedans or station wagons in addition to the RV's used for sleeping. They used these vehicles for such purposes as driving out of the area to stores, to fishing spots within the study areas, and to places where they could gather forest items such as mushrooms, berries, and firewood.

Frequently, especially in the Taneum-Manastash and Greenwater areas, one or more motorcycles or four-wheel drive vehicles were brought along in tow or in the backs of pickups to be used for recreation purposes. (see fig. 2).

Size of party.—Generally twice as many people were found in camping parties (about six) than in day-use groups (about three). This is consistent with the finding that camping parties had multiple vehicles more often than day users. Often camping parties were composed of multiple-family groups camping at the same site, which strengthens opportunities for intra-party socialization (fig. 11). The same holds true for both users of developed campgrounds and Wilderness Areas.

Length of stay (campers).—There was a significant difference in the length of stay by study area (table 9). The mean length of stay for respondents was: Greenwater 2.6 nights, upper Clackamas 3.8, and Taneum-Manastash 5.2. We believe the popularity of the Taneum-Manastash area for hunting accounts for the longer average stay; elk and deer hunters had been observed camping out for as long as 2 weeks. To test the notion, we divided the responses of the Taneum-Manastash campers into two groups: summer (July 1-October 15) and hunting (October 16-November 14, deer and elk season). The mean length of stay was 3.0 nights for summer campers and 7.8 for hunters, supporting the belief that the longer average length of stay for that area resulted from the influence of the hunters.

Table 9—Expected length of stay for campers by study area 1/

Study area	Mean number of nights
Greenwater	2.6
Taneum-Manastash	2/ 5.2
Upper Clackamas	3.8
All areas	4.1

1/ Based on the responses of 898 campers.
2/ 3.0 mean number of nights for 225 summer season campers; 7.8 for 194 hunting season campers.

Figure 11.—Camping parties are often multiple-family groups with several vehicles.

Participation in specific activities.—We asked respondents to indicate their activities while visiting the area. The results shown in table 10 indicate that all three areas serve a variety of purposes; each of the 39 activities listed on the questionnaire had some participants in each area. Activities receiving the greatest proportion of participants were:

Greenwater—Motorbiking, target shooting, day hiking (day users), berry picking, collecting forest items, camp chores (campers), visiting friends (campers), outdoor games (campers).

Taneum-Manastash—Operating four-wheel drive vehicles, snowmobiling, hunting, photography (day users), horseback riding, snowshoeing, getting food (day users), getting Christmas trees (day users), visiting other parties (campers).

Upper Clackamas—Driving, fishing, boating/canoeing, raft/river floating, mountain climbing, day hiking (campers), swimming, nature walks, photography (campers), snowplay (day users), getting food (campers), walking (day users), visiting-friends (day users), enjoying music, relaxing, outdoor games (day users), art work (campers), sunbathing, reading, playing cards.

Some interesting patterns are evident in these lists, which document the notion that each area—although similar to the others in terms of the extensiveness of activities—is different when intensity of participation is considered.

The upper Clackamas area had a higher frequency of participation in many more activities than either of the other areas, indicating that users come there for a wider variety of activities compared to the other areas. This might be expected because of the greater range of opportunities available than in the Greenwater and Taneum-Manastash areas. The upper Clackamas seems to cater to a more general-purpose user than do the other study areas.

Table 10—Percentage participation in recreation activities, by study area

	Greenwater 1/		Taneum-Manastash 2/		Upper Clackamas 3/	
Activity	Campers	Day users	Campers	Day users	Campers	Day users
Art work	6	4	5	5	11	7
Backpack	9	24	13	25	22	19
Bicycle	13	8	6	6	11	11
Boat/canoe	15	18	17	20	32	52
Climb mountain	14	19	14	19	21	40
Collect forest items	29	26	26	22	20	17
Collect rocks	30	24	23	27	33	20
Cross-country ski	2	5	2	8	5	7
Cut Christmas tree	8	13	12	24	13	11
Cut wood	22	30	21	41	23	26
Day hike	35	49	38	43	47	41
Do camp chores	85	68	79	70	79	77
Drink alcoholic beverages	35	24	28	25	34	16
Drive	44	56	46	57	50	73
Enjoy music	33	21	19	15	41	40
Fish	81	71	75	71	86	85
Four-wheel drive	24	28	36	33	12	10
Get food	15	29	19	31	22	13
Hunt	39	49	70	63	43	25
Motorbike	57	27	36	18	20	9
Nature walk	53	52	49	48	61	68
Photograph	26	28	30	33	37	27
Pick berries	46	57	32	46	39	34
Play cards	48	26	38	24	55	24
Play in snow	24	16	11	21	22	36
Play outdoor games	50	30	30	27	46	48
Raft/float river	13	12	5	13	27	16
Read	48	28	33	22	50	32
Relax	83	70	75	61	84	80
Ride horseback	12	10	17	20	13	7
Shoot targets	30	32	28	24	22	13
Snowmobile	10	7	12	15	4	2
Snowshoe	1	5	4	12	3	4
Sunbathe	44	25	25	20	46	27
Swim	31	28	20	24	53	58
Walk	84	69	71	60	82	80
View scenery	74	65	72	64	73	79
Visit friends	76	57	71	59	66	70
Visit other parties	20	21	28	18	22	15

1/ Based on the number of users who responded: campers 284; day users 375.
2/ Based on the number of users who responded: campers 419; day users 268.
3/ Based on the number of users who responded: campers 195; day users 639.

Some activities were more common in one area than in the other areas, attributable to available physical resources clearly distinguishing one area from another. Well-known motorcycle trails, berries, and gemstones in the Greenwater; four-wheel drive routes, prime hunting, easy access to Christmas trees and snow in the Taneum-Manastash; and main roads for driving, and an accessible river with reasonably good fishing in the upper Clackamas, all facilitate certain activities in one place more than they do in another. Indeed, as Burch (1965) indicated, people choose places that facilitate specific activities. (fig. 12).

Other activities seem to be related more to the type of user than to features of the area. Visiting friends and other parties, outdoor games, photography, horseback riding, nature walks, enjoying music, relaxing, art work, sunbathing, reading, and playing cards are possible in all areas, but each tends to appear more in one area than in the others.

The implications of the findings covered in this section seem clear. In areas such as those in our study, managers should recognize and protect features that offer different opportunities than other areas. Yet at the same time, one must avoid stereotyping areas as being good for one activity and not another. At least in the areas studied, many purposes are served for the visitors. Diversity is the key, and users seem to match their desired style to facilities of an area with little difficulty and few conflicts with other users.

Preferences for Recreation Setting

Many studies of outdoor recreationists focus on the respondent's preference of location. Although preferences are often an imperfect indicator of subsequent behavior (Clark 1977, Heberlein 1977, Webb and others 1966), they do give some indication of the motives behind certain recreation choices or satisfactions and values sought. Planners and managers can benefit knowing how and why recreationists make choices about where to go and what to do at a recreation site. Because management actions may facilitate or hinder recreationists' choices, data on preferences can help determine the range of public values (figs. 13A and 13B).

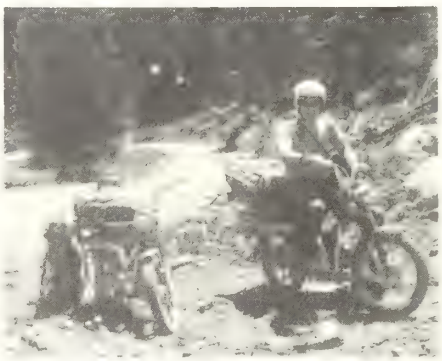

Figure 12.—All study areas offer a wide variety of recreational opportunities. In addition, each area provides unique physical resources that attract specific interests: *A*, The upper Clackamas area caters to a more general-purpose user and features a river with good fishing; *B*, The Greenwater area offers motorcycle trails, berry picking, and gemstones; *C*, The Taneum-Manastash area provides four-wheel drive routes, prime hunting, and easy access to Christmas trees.

Figure 13.—Knowing people's preferences helps managers determine the range of public interests and make better management decisions. For example, research shows that many users of developed campgrounds prefer socializing and having many comforts and facilities.

Figure 13B.—Most Wilderness Area users, however, prefer solitude with minimal or no conveniences.

The Recreation Opportunity Spectrum (ROS) framework is based on the assumption that recreationists seeking certain recreation experiences choose settings in keeping with their desires (Brown and others 1978, Clark and Stankey 1979b). Research on campers in developed areas and Wilderness Area users has documented that these two groups generally are at polar extremes from one another when it comes to preferences for recreation places. Users of developed, intensively used campgrounds tend to prefer socializing with many people outside of their own party; they desire many comforts and facilities in the campgrounds they frequent; and they are generally very tolerant of highly modified environments (Clark and others 1971, Hendee and Campbell 1969). Wilderness Area users, on the other hand, generally prefer

solitude with only minimal contacts with people outside their party, they desire areas without the trappings of modern civilization, and they prefer pristine environments with natural conditions (Hendee and Campbell 1969). Wilderness Area users, on the other hand, generally prefer solitude with only minimal contacts with people outside their party, they desire areas without the trappings of modern civilization, and they prefer pristine environments with natural conditions (Hendee and others 1978).

Clearly, the car campers in developed areas and Wilderness Area users have made choices, which put them at the two ends of the ROS. But did the users in our study choose the study areas because they had some special appeal, as indicated by their repeated use and length of stay, or because they could not find places more in keeping with their desires?

Settings preferred by users.—Results indicate there is a clear relationship between preferences and visitation to particular kinds of recreation settings. More than half the campers preferred environments much like the ones they were in when the questionnaire was given to them (table 11). Over 80 percent preferred either minimally developed campgrounds or dispersed, roaded areas.

Table 11—Users' first preference for types of recreation settings 1/

(In percent)

Type of setting preferred	Campers	Day users
Highly developed campgrounds 2/	4	11
Minimally developed campgrounds 3/	25	34
Dispersed, roaded areas 4/	62	34
Roadless backcountry or Wilderness Areas 5/	9	21
Total	100	100
Statistical summary	χ^2=175.49; p < 0.001; γ=-0.13	

1/ Based on the number of users who responded: campers 810; day users 1,135.
2/ Campgrounds or picnic areas with many facilities, such as paved roads, flush toilets, water faucets, tables, permanent fireplaces, and sometimes electricity and/or showers.
3/ Campgrounds or picnic areas with only rustic facilities, such as outhouses, tables, fireplaces, and water at a few central locations.
4/ Recreation areas where informal campsites have been established, but there are no official facilities.
5/ Areas where the only access is by hiking or horseback.

Day users, although indicating roughly the same order of preference, gave very different responses: only one-third gave dispersed, roaded areas as the firest preference. About equal numbers of day users preferred minimally developed and dispersed, roaded areas followed by backcountry or Wilderness Areas. A small proportion indicated their first preference as highly developed campgrounds.

Although some significant differences were noted between areas, these were largely a matter of degree rather than order. In all areas, a higher percent of respondents preferred dispersed, roaded recreation over minimally developed sites, but preferred minimally developed sites over backcountry. Least preferred by both overnight and day users in all areas were developed recreation sites.

Campers seem to come to dispersed roaded areas because they prefer them. But day users show an equal or stronger preference for other types of areas, which may explain why they use the areas during the day for a variety of recreational activities but do not camp there as frequently.

Number of trips to different settings.—As would be expected, based on the preference described above, people in the study visit dispersed, roaded settings more frequently than other settings (table 12). More than 90 percent of the campers and 80 percent of the day users had visited this type of setting, with more than a third visiting 6 times or more. Only a small proportion of the campers and day users did not visit dispersed, roaded settings during the year prior to responding to our questionnaire.

Table 12—Percentage of users visiting recreation settings during the year prior to the study, by type of setting and number of visits.

Type of setting and user group	Number of visits					Total	Statistical summary
	None	1-2	3-5	6-8	9 or more		
Highly developed campgrounds:							
Campers (N=800) 1/	50	33	12	3	2	100	χ^2=2.47; p < 0.65;
Day users (N=1,115)	50	32	12	3	3	100	not significant
Minimally developed campgrounds:							
Campers (N=795)	20	37	25	9	9	100	χ^2=3.15; p < 0.53;
Day users (N=1,140)	18	35	28	10	9	100	not significant
Dispersed, roaded areas:							
Campers (N=831)	7	22	31	16	24	100	χ^2=53.67; p < 0.001;
Day users (N=1,135)	16	27	23	12	22	100	γ=0.17
Roadless backcountry or Wilderness Areas:							
Campers (N=759)	64	18	10	4	4	100	χ^2=66.90; p < 0.001;
Day users (N=1,076)	45	25	13	7	10	100	γ=0.31

1/ Numbers in parentheses indicate the number of users who responded.

Highly developed campgrounds and roadless Wilderness Area/backcountry settings are clearly much less popular with recreationists visiting the study areas than minimally developed campgrounds and dispersed, roaded, recreation areas. About half or more reported that they did not use these other areas at all; most of the remainder visited them only once or twice. An exception (but consistent with earlier data) is that more day users reported going to roadless areas, and visited these areas more often, than did campers.

In addition to their strong preference for the dispersed areas, recreationists there also indicated they tended to use such areas more frequently than they did other types; the relationship between preference and actual participation was significant and strong. Although there was a positive relationship between preference and patterns of use, recreationists did use other types of recreation settings as well, again documenting the uncertain relationship between stated preference and actual behavior: perceived availability of alternatives, seasonal variation in access to preferred places, influence of family or friends, purpose of the trip, or the desire for diversity. As Shafer (1969) points out, there is no such thing as an average recreationist. In this case, variety may truly represent the spice of life for many of these people.

Childhood recreation participation.—To gain some insight about how recreationists learn about dispersed recreation, we asked respondents to indicate what type of forest recreation they participated in most often as children. Data in table 13 indicate that of those who camped as children, most went to the more dispersed, undeveloped areas; only about 10 percent of the users visited highly developed campgrounds most often as children. The latter setting may have been less available more than 20 years ago than at present, but the results do indicate that the majority of our sample camped as children in places similar to where they tend to camp now; a statistically significant relationship was found between childhood participation and present patterns of use. Similar findings have been documented by Yoesting and Burkhead (1973) fig. 14).

Table 13—Type of recreation setting users visited most when they were children[1/]

(In percent)

Type of setting	Campers	Day users
Highly developed campgrounds	10	9
Minimally developed campgrounds	27	31
Dispersed, roaded areas	31	28
Roadless backcountry or Wilderness Areas	19	20
Did not camp	29	26
Total	116	114
Statistical summary	$\chi^2=6.94$; $p \leq 0.14$; not significant	

1/ Based on the number of users who responded: campers 898; day users 1,262.
2/ Totals equal more than 100 percent because some respondents indicated more than one setting.

Figure 14.—The majority of the people sampled camped as children in places similar to those they tend to camp in now. Information about childhood recreation participation may give some insight about how users learn about dispersed recreation.

Future use of recreation settings.—What people say about their anticipated future behavior may also be a good indicator of their like or dislike (preference and/or commitment) for a particular type of recreation setting (Heberlein 1977). The majority of campers and day users indicate that their future use of highly developed, minimally developed, and backcountry areas will remain the same or decrease (table 14). But a majority of the campers and half of the day users say that their use of dispersed, roaded (but undeveloped) areas will increase. These data support the preferences described earlier and suggest that both day users and campers are committed to dispersed, roaded types af recreation opportunities and will use such areas more often in the future. In fact, data on recreation use gathered by the Forest Service nationally supports this finding.

Reasons for liking and disliking different recreation settings.—The format of the questionnaire permitted each respondent to list up to three reasons for liking and disliking each of the four types of recreation settings. Using procedures of content analysis developed for public involvement (Clark and Stankey 1976), the large number of differently worded, yet similar, responses was reduced to 29 basic reasons for liking each type of setting (table 15) and 28 reasons for disliking each type (table 16).

The responses shown in the tables are essentially positive and negative expressions of the same values. For example, in table 15, 15 percent of campers like dispersed, roaded recreation areas because they perceive such areas as not having too many people. In table 16, less than 1 percent of the respondents reported disliking these areas because of too many people. Together, the two tables provide an informative picture of the reasons this group of recreationists prefer less developed settings.

Both campers and day users gave only a few reasons for liking **highly developed campgrounds** (see table 15). A small minority of the sample liked the facilities associated with such areas and the fact that they are readily available. Negative comments, however, far outweighed positive ones. Highly developed campgrounds were viewed as being too crowded, too developed, too noisy, and too expensive. Previous studies of campground users found just the opposite: people choosing to camp there liked them for some of the same reasons dispersed area users disliked them (Clark and others 1971).

Table 14—Percentage of users expecting to visit recreation settings in the future, by type of setting and pattern of use

Type of setting and user group	Anticipated use compared to present practice			Total	Statistical summary
	Increase	Same as present	Decrease		
Highly developed campgrounds:					
Campers (N=783) 1/	15	62	23	100	χ^2=9.80; p ≤ 0.001;
Day users (N=1,108)	19	61	20	100	γ=-0.13
Minimally developed campgrounds:					
Campers (N=806)	32	60	8	100	χ^2=159.18; p ≤ 0.001;
Day users (N=1,160)	37	56	7	100	γ=-0.08
Dispersed, roaded areas:					
Campers (N=843)	62	34	4	100	χ^2=183.44; p ≤ 0.001;
Day users (N=1,132)	50	43	7	100	γ=0.24
Roadless backcountry or Wilderness Areas:					
Campers (N=761)	35	52	13	100	χ^2=14.99; p ≤ 0.001;
Day users (N=1,085)	45	44	11	100	γ=-0.14

1/ Numbers in parentheses indicate the number of users who responded.

Table 15—Percentage of users who like recreation settings, by reason and type of setting1/

Reason for liking	Highly developed campgrounds		Minimally developed campgrounds		Dispersed, roaded areas		Roadless backcountry or Wilderness Area	
	Campers	Day users	Campers	Day users	Campers	Day users	Campers	Day users
Not too many people	2/	2/	16	16	25	18	7	8
Developed	8	11	14	14	2	2	2/	2/
Not developed	2/	2/	9	11	13	12	5	8
Private	2/	2/	4	4	25	12	6	8
Peaceful	2/	2/	1	3	6	4	5	5
Lack of RV's 3/	2/	2/	2/	1	1	1	2/	1
RV's allowed	2/	2/	2	2/	6	3	1	2/
My style	2/	1	4	6	7	6	3	4
Like other users	2/	2/	1	2	1	1	2/	2
Accessible	2/	2/	1	2	5	6	2/	2/
Not accessible	2/	2/	2/	2/	1	2/	2/	2/
Preserve natural surroundings	2/	2/	2/	2	3	4	6	11
Few rules	2/	2/	2/	2/	2	2/	2/	2/
Clean	1	2	2/	2/	1	2/	2/	1
Can be used by all	2	5	5	6	3	3	1	2/
Do not use, but support	2/	2/	2/	2/	2/	2/	4	4
Feeling of discovery	2/	2/	2/	2/	1	2	3	5
Like to hike	2/	2/	2/	2/	2/	2/	6	6
Scenery	2/	2/	2/	2	3	3	6	5
Freedom	2/	2/	1	1	9	5	2	2
Like to hunt	2/	2/	2/	2/	3	1	2	1
Area is fun	2/	1	5	6	9	6	5	7
Not too expensive	2/	2/	1	2	3	2	2/	2/
Area is convenient	4	5	7	7	2	4	2/	2/

1/ Based on the number of users who responded: campers 898; day users 1,282. Only reasons given by 1 percent or more of the respondents for any of the recreation settings are listed. Other reasons given were: like rules and regulations, all cannot use, like because safe, can gather natural products, hunting not allowed.
2/ Less than 1 percent responded.
3/ RV=recreational vehicle.

Table 16—Percentage of users who dislike recreation settings, by reason and type of setting[1/]

Reason for disliking	Highly developed campgrounds		Minimally developed campgrounds		Dispersed, roaded areas		Roadless backcountry or Wilderness Area	
	Campers	Day users	Campers	Day users	Campers	Day users	Campers	Day users
Too many people	50	38	9	6	2/	2/	2/	2/
Too developed	20	21	3	3	2/	2/	2/	2/
Not developed enough	2/	2/	2/	2/	2	3	2/	2/
Lacks privacy	6	3	2	2/	2/	2/	2/	2/
Too noisy	4	5	2/	2/	2/	2/	2/	2/
Too many RV's 3/	1	2	2/	2/	2/	2/	2/	2/
Cannot use RV's	2/	2/	2/	2/	2/	2/	2	2/
Not my style	6	7	1	2/	2/	2/	1	1
Too expensive	5	5	2/	2/	2/	2/	2/	2/
Dislike other users	1	2	2/	2/	2/	2/	2/	2/
Not accessible	2/	2/	2/	2/	2/	2/	3	3
Destroys natural surroundings	2	4	2/	2/	2/	2/	2/	2/
Too many rules	3	2	2/	2/	2/	2/	2/	2/
Not clean	2/	1	2/	1	2/	2	2/	2/
Cannot be used by all	2/	2/	2/	2/	2/	2/	6	7
Do not hike	2/	2/	2/	2/	2/	2/	9	4
Vandalism in area	2/	1	2/	2/	2/	2/	2/	2/
Area not fun	1	1	2/	2/	2/	2/	2/	2/

1/ Based on the number of users who responded: campers 898; day users 1,282. Only reasons given by 1 percent or more of the respondents for any of the recreation settings are listed. Other reasons given were: too accessible, not enough rules, can be used by all, just not interested, too much Wilderness Area now, not enough Wilderness Area, not safe, no opportunity for hiking, not convenient, lack of freedom.
2/ Less than 1-percent response.
3/ RV=recreational vehicle.

People at the three study areas were more favorably inclined toward **minimally developed campgrounds** than highly developed ones. Many respondents see these settings as offering some of the advantages of more developed areas without the disadvantages. Examples of advantages include some facilities, convenience, and the fact that these areas are open to all regardless of the equipment they have, their skill at camping, or their physical condition. At the same time, they believe that minimally developed areas are less crowded, more private, more fun, and not as expensive to use as highly developed campgrounds A minority feel these areas are also too crowded and prefer more dispersed settings.

Few people gave reasons for disliking **roadless backcountry or Wilderness Areas,** but those that did felt that these areas were not readily accessible. Recreationists at our three study areas who liked roadless areas reported reasons generally similar to those given for dispersed, roaded areas and minimally developed campgrounds, but reported them less frequently. Some additional reasons for liking these settings centered around conservation and esthetic values such as preservation of natural surroundings and scenery, responses consistent with what previous research on Wilderness Area users has documented (Hendee and others 1978).

As might be expected, only a few people gave reasons for not liking **dispersed, roaded areas:** about 3 percent of the respondents felt these areas were not developed enough and 2 percent of the day users thought they were not clean enough. More people gave reasons for liking dispersed, roaded, recreation areas than for any one of the other three types. The questionnaires revealed that 25 percent of the campers liked dispersed areas because there were fewer people and they were private. About 12 percent of the campers and day users liked this type of recreation site because it was not developed. Other people reported that they valued the freedom to do what they wanted that existed in such areas and that it simply was their style, fun, peaceful, or inexpensive.

Respondents in the study were also asked about specific things that affect their use and enjoyment of dispersed, roaded areas. These topics represent positive elements of dispersed, motorized recreation that may be negative attributes of other types of recreation opportunities. The conclusion reached after examining these opinions and information presented earlier is that dispersed recreation settings have attributes that make them different from other types of recreation opportunities. Table 17 shows the several reasons for liking or disliking dispersed, roaded recreation areas.

Table 17—Reasons users like or dislike dispersed, roaded, recreation areas

(In percent)

Questionnaire statement and user group	Response: Disagree	Neutral	Agree	Total	Statistical summary
A. I visit dispersed, roaded areas partly because there are not enough developed campgrounds:					
Campers (N=882) 1/	78	9	13	100	χ^2=2.29; p < 0.32;
Day users (N=1,203)	73	16	11	100	not significant
B. One reason I prefer dispersed, roaded areas is because there is no fee charged for camping:					
Campers (N=890)	18	21	61	100	χ^2=1.20; p < 0.55;
Day users (N=1,222)	19	27	54	100	not significant
C. One of the values of dispersed, motorized recreation is that it is not regimented and controlled like other kinds of recreation:					
Campers (N=893)	6	10	84	100	χ^2=1.77; p < 0.41;
Day users (N=1,218)	7	16	77	100	not significant
D. One nice thng about dispersed, roaded areas is that campers can alter sites to accommodate the needs of their camping party (for example, build new fire ring, set up tables, change parking spaces):					
Campers (N=893)	8	11	81	100	
Day users (N=1,222)	16	20	64	100	χ^2=7.27; p < 0.26;
E. I visit dispersed, roaded areas to engage in activities not allowed or appropriate in developed recreation areas (for example, motorbiking, picking flowers):					
Campers (N=885)	33	15	52	100	χ^2=1.63; p < 0.44;
Day users (N=1,213)	39	18	43	100	not significant
F. I view the challenge of exploring little-used back roads as an attraction of dispersed, roaded areas:					
Campers (N=890)	5	8	87	100	χ^2=0.53; p < 0.87;
Day users (N=1,217)	5	11	84	100	not significant
G. One value of dispersed, roaded areas is the chance to camp, picnic, or play away from people not in my party:					
Campers (N=887)	3	7	90	100	χ^2=2.10; p < 0.35;
Day users (N=1,219)	5	12	83	100	not significant

1/ Numbers in parentheses indicate the number of users who responded.

1. Lack of developed campgrounds—In our earlier studies of recreation use along forest roads, some managers believed the areas were used by campers only because there were an insufficient number of developed campgrounds. The data from this study indicate that is not the case: over 70 percent of both day users and campers disagreed. Our observations during the study indicated that nearby campgrounds were empty or partially full. Obviously there was something special about these areas that brought recreationists to them.

2. Lack of fees.—Campers and day users agreed (about 60 percent) that lack of fees does influence their preference for dispersed, roaded recreation areas. The unanswered question is how much of their recreation behavior is influenced by lack of fees? If, indeed, dispersed, motorized recreation has some unique appeal for those who participate in it, then we suspect that people might still accept some sort of fee, just as people in developed areas do.

3. Lack of regimentation—In contrast to developed recreation sites, and even to some Wilderness Areas, the three dispersed, roaded areas under study have few formal contols over user behavior.

Recreationists are generally left on their own to manage their behavior and any conflicts that may arise. A high proportion of both day users and campers (77 and 84 percent) indicate that lack of regimentation is one of the values of this type of recreation (Clackamas day users differed significantly from the other users by indicating less support for this statement). Consequently, if additional rules and regulations were instituted in such areas, it is possible that user satisfaction might decline if those rules hinder goals defined as appropriate by these recreationists.

4. Ability to alter sites—Campsites in the three study areas are characterized by a general lack of facilities or management. Recreationists are often observed moving campfire rings, erecting shelters or temporary outhouses, or moving logs and rocks to facilitate access to the sites. In so doing, they are able to accommodate the site to their own group activities. There was strong agreement that being able to alter sites is an important attribute of dispersed, roaded areas. In our study, there was much higher agreement among campers (82 percent) than day users (63 percent). This is logical because day users generally would require fewer site modifications to suit their needs than would campers. These data suggest that users would not like management actions that would make it more difficult to alter sites (permanent fire rings for example). Significant differences were noted between the areas for both campers and day users. For both populations, support for altering sites was strongest in the Greenwater, followed by Taneum-Manastash and upper Clackamas. In all cases, though, most users preferred being able to alter sites to meet their needs (fig. 15).

5. Allows certain recreation activities—When choosing an area as a location to engage in certain activities, recreationists must learn if the activities are allowed, and if so, under what possible restrictions or limitation. Motorcycles, for example, can be driven through a campground in most developed areas but not around camping sites or on trails. In dispersed, roaded areas, however, there are generally few restrictions if the terrain is suitable for the activity. About half the campers and day users said they came to the study areas to do things they could not do in developed recreation areas. This reason was most prevalent for campers in the Greenwater (69 percent) and Taneum-Manastash (53 percent) areas, where motorcycling and operating four-wheel drive vehicles are major activities. Only 31 percent of the upper Clackamas users visited that area for the same reason. Although day users in all areas shared the same view, it was not as strong as that of campers.

6. Exploring little-used roads—By definition, roads are necessary for vehicle access indispersed, roaded areas. But roads may also have some intrinsic appeal in themselves. The areas under study have many miles of roads, including high-standard paved roads that often become unpaved roads and then skid roads or informal tracks suitable for four-wheel drive vehicles. There was strong agreement by both day users (83 percent) and campers (88 percent) that exploring such roads was an attraction of dispersed motorized recreation. (For day users, slighly stronger support was found in the Greenwater area, followed by the Taneum-Manastash and upper Clackamas areas.) Perhaps there is an analogy between the hiker who explores on foot and the biker, four-wheel drive enthusiast, or car driver who uses a vehicle on the many miles of available roads in dispersed, roaded areas. They may be out for the same experience but seek it in a different style. It was by such exploring that many of the respondents found the recreation areas in the first place (fig. 16).

7. Getting away from others—Intensively used developed campgrounds are characterized by frequent (and often actively sought) interaction between people from different parties (Clark and others 1971 and Campbell 1969). The opposite is true in primitive recreation settings; such contacts are usually not desirable and are infrequent, although intraparty socialization appears very important (Burch and Wenger 1967, Hendee 1967, Hendee and others 1978, Stankey 1973). But what about dispersed, roaded areas? Table 17 (item G) and 18 show how recreationists in these areas feel about getting away from others in general and at their campsites. Getting away from others is important: more than 80 percent of both day users and campers agree. And in choosing campsites, about two-thirds want to be completely away from other campers; less than 5 percent want to be close enough to visit.

Figure 15.—Most recreationists enjoy having the freedom to alter their campsites to suit their particular needs.

Figure 16.—Exploring roads is one of the biggest appeals of dispersed recreation.

Hendee (1967) asked the same question of users in National Forest and National Park campgrounds and Wilderness Areas. Although some slight differences were found in that study between users of each type of area, those results are consistent when compared to findings from our study. Users of dispersed, roaded areas fall neatly between the car campground users and Wilderness users. That is, they prefer to get away from others more than campground users, but not as much as do Wilderness visitors.

The similarity between campers and day users is striking in this regard. Some people have hypothesized that most day users camp in neighboring developed campgrounds and only use the local, dispersed areas as playgrounds during the day. The data suggest this is not the case. When we asked day users where

Table 18—Relationships users prefer between campsites[1/]

(In percent)

Relationship preferred	Campers	Day users
One that is far away from other campers not in my party	66	65
One with a few other campers around that are not in my party	24	24
One where I can visit and talk with campers in other parties	3	4
Do not care	7	7
Total	100	100
Statistical summary	$\chi^2=3.55$; $p \leq 0.32$; not significant	

1/ Based on the number of users who responded: campers 873; day users 1,222.

Table 20—Reasons users decided to visit study area where they were contacted, by rank[1/]

Rank	Reason given by campers	Percent stating reason	Reason given by day users	Percent stating reason
1	Familiar with area	42	To sightsee in vehicle	23
2	To hunt	23	To fish	20
3	Close to home	20	Familiar with area	20
4	Uncrowded	20	Close to home	14
5	To motorbike	15	To hunt	14
6	To camp	15	To collect firewood	9
7	To sightsee in vehicle	11	To explore area	6
8	To fish	10	To gather berries	4

1/ Based on the number of users: campers 898; day users 1,282. Questionnaire allowed users to state up to five reasons.

they came from before entering the study areas (home, a developed campground, or another dispersed area), 90 percent indicated that they came directly from home (table 19). It appears that both campers and day users were drawn to the area by the attributes of its setting, not because of the unavailability of some other type of area.

Reasons for visiting the study area.— Recreationists were asked to explain why they decided to visit the area where they were surveyed. A variety of reasons were given (table 20); although there were statistically significant differences between overnight and day users, most of the same reasons were given by both groups but were ranked differently. The reasons are of two types: those related to the area (familiar with area, close to home, and uncrowded) and those related to specific activities (hunting, fishing, motorbiking, camping, sightseeing, collecting firewood, gathering berries, and exploring).

Table 19—Origin of day users before they entered study areas[1/]

(In percent)

Origin	Day users
Residence	90
Developed site	6
Other dispersed site	4
Total	100

1/ Based on the responses of 1,106 day users.

Characteristics of preferred sites.— Much of the information generated as a result of this study addresses the general type of recreation settings preferred by users of the three study areas. During their visit to dispersed, roaded areas, campers and many day users spend much of their time at the specific, identifiable sites described in table 2. In their response to an open-ended question, campers and day users indicated that they looked for a variety of characteristics in a site when selecting a campsite (table 21).

Recreationists in the sample considered four criteria when choosing a campsite: positive and negative characteristics were mentioned more frequently than either specific facilities (discussed in the next section) or activities. Both campers and day users felt that access to water was the single most important factor when choosing among campsites. Lime (1971) noted a similar preference among developed campground users in the Lake States and Lucas (1964) found that Wilderness Area campers also preferred sites located adjacent to water. The Code-A-Site data for the three study areas clearly show that the most popular sites are those located near water and streams (84 percent) (table 2). Further analysis reveals that sites lacking water are generally used only during crowded periods, such as during holiday weekends, and for special purposes like hunting (Hendee and others 1976b) (fig. 17).

Table 21—Criteria considered by recreationists in selecting a campsite within a dispersed, roaded area

(In percent)

Criteria, characteristics, or features considered	Campers	Day users
Characteristics recreationists seek: 1/		
Access to water	65	46
Presence of trees	26	17
Level area for tent or RV 2/	18	12
Scenery	9	10
Access to firewood	7	5
Shade present or nearby	5	4
Large site	4	3
In a natural state	2	2
Good off road parking	1	1
Grazing for livestock	1	1
Characteristics recreationists avoid: 3/		
Near people outside own party	23	20
Trashy	8	9
Near main road	6	6
Difficult access	4	4
Noisy	2	4
Hazardous for children	2	2
Windy	2	2
Too many trees	1	1
Wet	1	1
Dusty	1	1
Facilities available: 3/		
Fire site	7	6
Sanitation	3	5
Tables	2	2
Garbage cans	1	1
Water	1	1
Activities the site permits: 1/		
Access to fishing	5	5
Good hiking nearby	3	3
Close to bike trails	2	1
Wildlife viewing	1	1
Activities available (general)	1	1
Shooting	1	1
Access to forest items	1	1

1/ Based on the number of users who responded: campers 898; day users 1,282.
2/ RV=recreational vehicle.
3/ Based on the number of users who responded: campers 882; day users 1,282.

Figure 17.—Access to water was determined as the single most important factor in choosing a campsite.

Other positive features important to users are the presence of trees on a site, a level spot for a tent or RV, and scenery. Other informal contacts with recreationists indicated that trees were desirable for a variety of reasons including protection from the weather, privacy, and esthetics (fig. 18).

Undesirable features also play a critical role in site selection. More than 20 percent of the recreationists sampled mentioned that they wanted to camp away from people not in their party. Others wished to avoid "trashy" campsites, those close to main roads, and sites with difficult access (difficulty, of course, depends on individual definitions).

Table 22 shows preferences for facilities respondents would like provided in dispersed, roaded areas. These data show the general unimportance of facilities, with the exception of toilets and trash cans. Nearly half the campers and about one-fourth of the day users indicated "none"—they liked the areas the way they were. The results of this study indicate mixed support for facilities. Several points should be made:

1. Day users were more inclined to favor facilities than campers. Perhaps this explains why the day users do not camp there; in other words, they prefer more comforts and conveniences.

2. Some campers preferred to have more facilities, but camp there anyway; a practice probably related to the difference between what people prefer and what they find acceptable. Obviously, people who continue to camp in such areas find

Table 22—Facilities users would like provided in the dispersed, roaded area where they were contacted[1/]

(In percent)

Facility	Campers	Day users	Statistical summary
None, I like thing as they are	42	31	$Z=4.95$; $p \leq 0.001$
Garbage cans	43	48	$Z=-2.25$; $p \leq 0.02$
Toilets	36	44	$Z=-3.60$; $p \leq 0.001$
Centrally located drinking water	19	31	$Z=-5.40$; $p \leq 0.001$
Central sewage disposal	12	16	$Z=-1.80$; $p \leq 0.07$; not significant
Permanent fireplaces at sites	12	22	$Z=-4.50$; $p \leq 0.001$
More developed campsites	5	7	$Z=-0.90$; $p \leq 0.37$; not significant
Horse corrals 2/	1	2	$Z=-0.45$; $p \leq 0.65$; not significant
Signs	3/	3/	

1/ Based on the number of users who responded: campers 881; day users 1,192.
2/ A write-in response.
3/ Less than 1 percent

Figure 18.—The presence of trees, a level spot for a tent or RV, and scenery are important features to users.

the absence of facilities acceptable or they would go elsewhere.

3. If managers followed user preferences, they might change the nature of the opportunities enough to change user patterns. For example, if trash cans, toilets, and other conveniences were installed, the day users who presently do not camp in such areas (because lack of such conveniences is unacceptable to them) might then begin camping there, thus competing with current campers who find the lack of facilities acceptable. Some campers we contacted said they would like to have more facilities, until they recognized the effects this might have on the use of their favorite area—that more people with different goals might come there. They recognized the reality of the invasion/succession process (Clark and Stankey 1979b, Clark and others 1971) and concluded they liked things just as they were. These data are a good example of the difficulty inherent in using preferences in making decisions about recreation management (Driver and Bassett 1977). The key in both cases seems to be insuring that a full spectrum of opportunities is available so all users can choose the type they like best.

Recreationists' Perceptions of Management Problems

Recreationists in the three study areas were asked to indicate how important certain problems are in dispersed, recreation areas, and what sort of procedures they preferred for controlling such problems. In general, respondents did not believe there were many problems (table 23 and 24).

Fire danger.—Opinions were split on whether or not there is a great danger of recreationists starting fires (table 23). Day users were more likely to agree that this is a problem (48 percent) than were campers (35 percent). Apparently campers are more confident in their ability to work with fire in the woods than are day users. A study of actual occurrences of fire in Washington and Oregon indicates that the risk associated with dispersed recreation is relatively low and that campers often discover, report, and put out fires before agency personnel reach the scene (Hogans 1979).

Crowding.—Depending on who responded, crowding is or is not a perceived problem. All three areas are characterized as having a few locations in which use is relatively dense, with overnight areas in the Greenwater the most concentrated. Use is generally spread over a large amount of space in the Taneum-Manastash and upper Clackamas areas.

Slightly under half the campers (43 percent) felt that some control would soon be needed in the area where they were staying during the study (table 23). Campers in the upper Clackamas area were more likely to foresee the need for control followed by campers in the Greenwater and Taneum-Manastash areas. A large number of both campers and day users were neutral on this issue (22 and 25 percent).

Safety.—One of the traditional concerns of recreation managers is for the safety of the forest visitor. The areas studied present a variety of potential hazards: hot springs, poisonous snakes, falling trees, logging traffic, and threats from other users to people and property.

Respondents in the study seemed generally unconcerned about safety hazards (table 23). The majority do not feel unsafe when camping or picnicking in dispersed, roaded areas, although upper Clackamas users tended to agree more than those from the other areas that safety is a concern. The majority do not believe there is a hazard from logging traffic, and even those who do see it only as "becoming" more of a problem (38 percent campers, 40 percent day users) rather than something of major concern at present (less than 10 percent) (table 24). Whether or not these perceptions result from users being unaware of problems or from their good fortune in the past is unknown.

Even though recreationists in the three areas seemed generally unconcerned about safety hazards, they did express on overwhelming sentiment that they be

Table 23—Users' opinions about certain management problems in dispersed, roaded, recreation areas

(In percent)

Questionnaire statement And user group	Response: Disagree	Neutral	Agree	Total	Statistical summary
A. There is a great danger of recreationists accidentally starting a forest fire in dispersed road recreation areas:					
Campers (N=884) 1/	48	17	35	100	χ^2=47.04; p ≤ 0.001;
Day users (N=1,224)	34	18	48	100	γ=0.25
B. At popular dispersed sites in this area some kind of control will soon be needed to reduce crowding:					
Campers (N=887)	35	22	43	100	χ^2=52.91; p ≤ 0.001;
Day users (N=1,224)	21	25	54	100	γ=0.25
C. We sometimes feel unsafe when camping or picnicing is dispersed, road recreation areas:					
Campers (N=882)	75	11	14	100	χ^2=28.22; p ≤ 0.001;
Day users (N=1,215)	64	17	19	100	γ=0.23
D. The Forest Service should alert users about potential hazards (for example, poisonous snakes, dangerous roads, polluted water, etc.) in dispersed road areas:					
Campers (N=890)	6	6	88	100	χ^2=4.74; p ≤0.19;
Day users (N=1,237)	7	8	85	100	not significant

1/ Numbers in parentheses indicate the number of users who responded.

alerted about potential hazards (85 percent of the day users and 88 percent of the campers) (table 23). This expression does not contradict their desire for lack of regimentation; it only says they want to be made aware of potential problems (fig. 19).

Dust from gravel roads.—Most roads in the three areas are not paved; truck and car traffic creates dust at times. Managers often suggest that dust is a problem for recreationists, but about half the sample felt it was not. There was less agreement in the Greenwater area, probably because of the heavy volume of fast moving logging traffic on the mainroad, which is close to most of the campsites. These data confirm that where dust is a problem, recreationists will report it as such.

Figure 19.—Although dispersed recreation users prefer the lack of regimentation, they do want to be alerted to potential hazards in an area.

Noise from motorcycles.—Although the upper Clackamas area has little motorcycle use, both the Greenwater and Taneum-Manastash areas have considerable activity. Opinions varied between day users and campers as to whether noise from motorcycles is a problem; day users perceive a much greater impact than do campers. Perhaps that is one of the reasons day users do not camp there.

The concept of "variable threshold" or "threshold of disruption" helps us understand this issue. For people who define motorcycle use as acceptable or who use an area expecting such use, the level of "acceptable noise" is probably higher than for others whose values and expectations are inconsistent with motorcycle use. Furthermore, the mere presence of this activity may be more important and detracting to some users than the noise level per se. Consequently, the level of motorcycle use and resulting "noise" (a personal judgment) is less important than

Table 24—Users' opinions about management problems within the dispersed, roaded area where they were surveyed

(In percent)

Problem	Response: Now a problem	Becoming a problem	Not now a problem	No opinion	Total	Statistical summary 1/
A. Dust from gravel roads:						
Campers (N=882) 2/	4	34	55	7	100	χ^2=8.60; p ≤ 0.035;
Day users (N=1,197)	5	34	51	10	100	γ=-0.05
B. Noise from motorbikes:						
Campers (N=883)	13	37	45	5	100	χ^2=75.77; p ≤ 0.001;
Day users (N=1,209)	20	44	28	8	100	γ=-0.30
C. Vandalism to personal or public property:						
Campers (N=881)	8	32	52	8	100	χ^2=186.78; p ≤ 0.001;
Day users (N=1,207)	19	44	23	14	100	γ=-0.49
D. Theft of equipment:						
Campers (N=879)	5	29	57	9	100	χ^2=131.68; p ≤ 0.001;
Day users (N=1,206)	11	37	34	18	100	γ=-0.41
E. Conflicts between recreation users (for example, hikers versus trailbikers):						
Campers (N=879)	5	35	49	11	100	χ^2=91.00; p ≤ 0.001;
Day users (N=1,191)	10	43	30	17	100	γ=-0.37
F. Lack of nearby stores, gas stations, and restaurants:						
Campers (N=881)	3	14	76	7	100	χ^2=11.54; p ≤ 0.009;
Day users (N=1,204)	3	16	70	11	100	γ=-0.09
G. Lack of directional signs on roads:						
Campers (N=876)	5	26	62	7	100	χ^2=12.95; p ≤ 0.004
Day users (N=1,198)	6	33	54	7	100	γ=-0.15
H. Lack of maps:						
Campers (N=873)	8	32	47	13	100	χ^2=3.16; p ≤ 0.37
Day users (N=1,204)	10	31	44	15	100	not significant
I. Danger of accidents with logging traffic:						
Campers (N=881)	3	38	48	11	100	χ^2=26.82; p ≤ 0.001
Day users (N=1,201)	6	40	39	15	100	γ=-0.18
J. Litter or garbage around campsites:						
Campers (N=887)	5	54	40	1	100	χ^2=95.61; p ≤ 0.001
Day users (N=1,210)	10	63	23	4	100	γ=-0.36

1/ γ was calculated on all responses except "no opinion."
2/ Numbers in parentheses indicate the number of users who responded.

the expectations of the users of the area in question. This issue and procedures for managing recreation impacts, including noise, are discussed in more detail in Clark and Stankey (1979a) and Harrison and others (1980).

Vandalism and theft.—The distinction between day user perceptions of vandalism and theft and those of campers is evident (table 24). More day users perceive vandalism and theft to be a problem than do campers, and more upper Clackamas campers felt that way than did campers in other areas. Perhaps more of the day users work or live in or near the area and are familiar with property theft and damage to logging equipment. In both groups, more respondents perceived vandalism as a problem than theft. How perceptions of recreationists compare to those of managers are discussed in Christensen and Clark (1979).

Conflicts between recreation users.—With the general lack of regulation in the three areas, it might be expected that conflicts would occur between recreation users, especially because there are so many types of activities. But this does not seem to be the case when user perceptions are examined. The difference between campers and day users is evident: day users see conflicts as more of a problem than do campers, perhaps explained by the backcountry orientation of the day users where encounters with other people are not as likely to occur (see table 15). This, too, may be one of the reasons day users do not camp in dispersed, roaded areas. Or, perhaps, day users have different sorts of conflicts with others than do campers.

In general, our observations and these data suggest that dispersed, roaded areas are relatively self-regulating. Each type of user tends to find their particular niche, and through such self-selection, minimize conflicts. For example, in one area of the Taneum-Manastash, motorcyclists and horse users are often seen sharing the same meadow—one group at each end. This is done here and elsewhere without formal regulation or zoning.

Lack of services and information.—As in most other respects in dispersed, roaded areas, recreationists are on their own with regard to bringing food and gas and finding whatever information they need. When we asked whether lack of stores, restaurants, and gas stations was a problem, the overwhelming response was that it is not (table 24). This supports earlier data suggesting that part of the appeal of such areas is the lack of developments, facilities, and conveniences. If that were not the case, they would probably go somewhere else (fig. 20).

A similar response, although not quite as strong, was found when we asked about the lack of directional signs. Most said it was not a problem. This may be related to the desire for exploring backcountry roads where directional signs may be a negative factor for some people. Somewhat stronger support for signs was found by campers in the upper Clackamas area than in the other areas, perhaps because of relatively less familiarity with the area than others have in their areas.

So concern was expressed, however, about a lack of maps. This is consistent with other responses—a large number of people want more maps that would aid their exploration. Another explanation might be that maps cannot impact a site as signs may for some users (fig. 21).

Danger of accidents with logging traffic.—Logging was taking place in each of the three study areas during the time of the study. In the Greenwater, a wide logging truck traveled down the main road every few minutes. Results show that most users did not regard logging trucks as a hazard. Approximately 5 percent considered logging trucks to be a problem, while about 33 percent thought trucks were becoming a problem. A possible explanation for this attitude is that logging generally did not take place during the weekends when most recreationists were present.

Figure 20.—Lack of facilities such as stores, restaurants, and gas stations is considered a positive rather than a negative feature of dispersed recreation use. Users simply bring their own supplies.

Figure 21.—Maps to assist in forest road exploration are generally preferred over directional road signs.

Litter and garbage.—A majority of both day users and campers believe that litter or garbage around campsites is becoming a problem. One reason is that they sometimes have to clean a site up when they arrive. The field assistants reported incidents where campers showed them bags of trash they had collected.

An observation study at the Greenwater area during the same study period found litter and garbage not to be a major problem, although some sites have user-established garbage pits. Nearly 90 percent of the campers packed out their garbage and a few users left garbage bagged or boxed at the fire ring. During the night, wildlife often scattered the contents throughout the camp. Some Forest Service fire patrols occasionally remove litter and garbage from recreation sites. For the most part, however, user-established sites were not maintained by the agency during the study period.

Litter does increase at campsites during the summer, but it does not seem to be a serious problem. The Litter Incentive System was used by the field assistants at Greenwater and demonstrated that many campers will help clean up their sites when asked to do so (Clark 1976, Muth and Clark 1978). Yet it might be necessary to educate dispersed area users on the adverse impacts caused by litter and garbage. Wilderness sanitation education is extensive (Hendee and others 1978), and strategies similar to the Forest Service's "no trace camping" policy might be used for dispersed recreationists (fig. 22).

Figure 22.—Litter or garbage around campsites is regarded as a problem by a majority of day users and campers. In the Greenwater area, however, responsible campers and litter incentive programs are keeping the problem under control.

Sanitation.—Resource managers, planners, and researchers are becoming increasingly concerned with environmental impacts produced by recreationists in dispersed recreation areas (Aukerman and Springer 1976, Downing and Moutsinas 1978, Lee and others 1970). One problem is the impact of human body waste on water quality. Lack of sanitary facilities in dispersed, roaded areas may be acceptable to some users but may contribute to conditions that could affect users' health and recreational enjoyment of the area.

The Taneum-Manastash area has four minimally developed sites with pit toilets. No facilities exist at dispersed sites along the State highway in the upper Clackamas area but toilets are available at the many developed campgrounds. No toilet facilities exist in the Greenwater.

Results of the study suggest that the potential for health and esthetic impacts from human waste does exist: 39 percent of the campers and 75 percent of the day users had no toilet facilities with them. More than in the other areas users at Greenwater reported they had equipment that made them self-contained.

Campers and day users were asked if they perceived the presence of human body waste near campsites as a serious threat to human health, water quality, and recreation enjoyment of the area (table 25). Opinions were generally mixed; about equal numbers agreed and disagreed. The large neutral response may be the result fo a lack of knowledge about the problem or perhaps a reluctance to comment. A social and biological study conducted at the Greenwater area during the same peiod focused on the effects of dispersed recreation on water quality (Christensen and others 1979). Evidence of fecal pollution was intermittent and the isolation of *Salmonella arizonae* from the relatively clean watershed was localized, suggesting that potential health hazards do exist. Providing information to users about such conditions may be important, particularly because most users want to be informed of hazards. Some statistically significant differences were found between areas, but these were mostly small and unimportant.

A substantial number of campers (39 percent) and day users (52 percent) agree that human body waste is a threat to water quality. The water quality study in the Greenwater watershed found deterioration of water quality on weekends, when use was heaviest, as distinguished from weekdays (Varness and others 1978). The effects on water quality at specific sites by the number of people, self-contained vehicles, and rain were inconclusive (Christensen and others 1979).

The most concern for both day users and campers was the impact of human waste on the recreational enjoyment of the area. Almost half of the campers (44 percent) and over half of the day users (56 percent) agreed that it was a serious threat. Human waste was observed at most of the campsites in the Greenwater area; the majority was found less than 75 feet from the fire ring. Some campsites had up to 11 different human waste areas, found anywhere from onsite to trails offsite.

Users were asked if disposal of human body waste was not a problem because nature quickly takes care of it (table 26). The high response of users who either believed decomposition was quick or were neutral may be the result of their lack of knowledge. Little public information is available on decomposition rates and appropriate method of disposal. Management practices today recommend digging holes 8-10 inches in diameter and no deeper than 6-8 inches (Hendee and others 1978). The recommendation may vary between region and/or agency. In fact, little objective information is currently available about the effects of specific burying practices in different environments.[2]

[2] Sanks, R. L.; Temple, K. L. Final report on liquid and solid waste disposal. In: U.S. forest lands, Bozeman, MT: Montana State University; 1975; Grant FS-INT no. 7 [U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; Ogden, UT].

Table 25—Users' opinions about human body waste near campsites threatening the quality of the dispersed, roaded area where they were contacted

(In percent)

Questionnaire statement, quality threatened, and user group	Response: Disagree	Neutral	Agree	Total	Statistical summary
The presence of human body waste near campsites in the dispersed, roaded area is a serious threat to:					
A. Human health					
Campers (N=872) 1/	47	18	35	100	χ^2=39.23; p $\leq$ 0.001;
Day users (N=1,206)	33	20	47	100	γ=0.24
B. Water quality					
Campers (N=874)	44	17	39	100	χ^2=58.32; p $\leq$ 0.001;
Day users (N=1,206)	28	20	52	100	γ=0.27
C. Recreation enjoyment					
Campers (N=878)	42	14	44	100	χ^2=36.98; p $\leq$ 0.001;
Day users (N=1,212)	29	15	56	100	γ=0.23

1/ Numbers in parentheses indicate the number of users who responded.

Table 26—Users' opinions about whether or not the disposal of human body waste in dispersed, roaded areas is a problem[1]/

(In percent)

Questionnaire statement and responses	Campers	Day users
The disposal of human body waste is not an important problem in dispersed road recreation areas because nature quickly takes care of it:		
A. Disagree	43	49
B. Neutral	15	16
C. Agree	42	35
Total	100	100
Statistical summary	χ^2=13.39; p $\leq$ 0.001; γ =-0.12	

1/ Based on the number of users who responded: campers 876; day users 1,214.

Many users in this study are not concerned about streams being polluted in the areas: they drink the water (table 27). But a companion study in the Greenwater found *Salmonella arizonae* and increased fecal coliforms intermittently. Still, according to bacteriological standards established by the State of Washington, the surface waters were found to be AA—acceptable for general recreation esthetic enjoyment (Washington Department of Ecology 1978). Water used for drinking, however, should contain less than 2 total coliforms per 100 milliliters. The evidence of pollution in the relatively clean water of the watershed suggests that potential health hazards exist and that managers need to prescribe appropriate practices regarding drinking water from the streams. In many places, including backcountry, users are encouraged to boil or treat water prior to drinking it (fig. 23).

Presence of domestic dogs.—In many developed campgrounds and in a growing number of parks and Wilderness Areas, dogs are either prohibited or must be physically controlled. No such regulations exist in dispersed, roaded areas, and the perception seems to be that these are

places where dogs can roam free without impacting people. We found in this study that nearly half the campers (44 percent) and a third of the day users (31 percent) had one or more dogs with them; many of the dogs were allowed to run loose (62 percent of camper's dogs and 54 percent of day users'). In areas where use is concentrated, the potential does exist for conflicts between parties because of dogs. Our experience over 5 years in these areas, however, suggests impacts are minor. But there is concern on the part of some managers that with the presence of human waste around many of the sites, dogs may act as a carrier for diseases.

Users' versus managers' perceptions of problems.—Results of our study indicate that users generally do not perceive many of the problems discussed to be of serious consequence. But the view of managers is quite different. In a companion study, managers were asked to rate the importance of the same problems (Downing and Moutsinas 1978). In almost all cases managers indicated a greater concern than did users (table 28). These results are discussed in more detail in Downing and Clark (1979).

Figure 23.—Most users reported they were not concerned about pollution in streams—they would drink the water. Evidence of some pollution, however, suggests potential health hazards; managers may have to prescribe methods of disposal.

Table 27—Users' practice of drinking water from possibly polluted streams[1/]

(In percent)

Questionnaire statement and response	Campers	Day users
Because it may be polluted, I do not drink the water from the main stream in this area:		
A. Disagree	62	48
B. Neutral	11	14
C. Agree	27	38
Total	100	100
Statistical summary	$\chi^2=45.13$; $p \leq 0.001$; $\gamma=0.27$	

1/ Based on the number of users who responded: campers 885; day users 1,236.

Table 28—Percentage of managers and users who perceive certain impacts as serious, somewhat serious, or becoming serious[1/]

Impact	Managers	Users
Litter/garbage	92	50
Vandalism	91	37
Danger of fire	86	40
Theft of equipment	86	27
Danger of accidents with logging traffic	81	29
Conflicts between recreationists	55	32
Presence of human waste near recreation sites	64	29
Water quality problems from human waste	44	43
Human health problems from human waste	39	40

1/ Based on the number of managers and users sampled: managers 663; users 2,180.

Such differences have also been found between managers and users of developed campgrounds (Clark and others 1971; Lucas 1970) and in Wilderness Areas (Lucas 1964). Explanations for the differences include the possibility that managers have more information about the real nature and extent (magnitude) of the problems, or that managers and users agree on the magnitude of the problems, but disagree on how important they are (Clark and Stankey 1979a, 1979b). Whatever the reason for the difference, users should be informed about the nature of specific problems before managers attempt to control the problems.

Attitudes About Forest Management Activities

Recreation along forest roads has been occurring for many years. But, the importance of this type of recreation has been recognized only recently by some managers. In many instances such use has been ignored until a problem occurs. Many managers still believe that the costs outweigh the benefits (Downing and Clark 1979, Downing and Moutsinas 1978). We asked respondents in the study to share their attitudes regarding certain types of forest mangement activities. Their comments are summarized.

Priority of dispersed, roaded areas.—The findings presented thus far show that most respondents favor dispersed, roaded areas over other types of areas, such as developed campgrounds. When we asked people if dispersed, roaded areas should have higher priority for managers than establishing developed campgrounds, less than 20 percent disagreed (table 29). From data gathered, the study demonstrates that dispersed, motorized recreation has its own clientele and occupies an important niche along the Recreation Opportunity Spectrum (Brown and others 1978, Clark and Stankey 1979b).

Road management.—Roads and how they are managed play a key role in defining the nature of recreation opportunities. Without roads, the kind of recreation under investigation in this study would not be possible. The majority of roads in National Forests that provide recreation opportunities are the result of timber mangement (Hendee 1974). Many resource managers recognize the dual role of these road systems, but how the roads should be managed for recreation purposes has not been determined. We asked users of dispersed, roaded areas about a variety of issues related to road management; their opinions are summarized in table 30.

Table 29—Users' attitudes about priority of management for dispersed, roaded areas versus developed campgrounds in National Forests[1/]

(In percent)

Questionnaire statement and response	Campers	Day users
Dispersed road recreation activities should be a higher priority than developed campgrounds on National Forest lands:		
A. Disagree	13	19
B. Neutral	23	27
C. Agree	64	54
Total	100	100
Statistical summary	χ^2=22.11; p $\leq$0.001; γ =-0.19	

1/ Based on the number of users who responded: campers 883; day users 1,210.

Over half the campers and a third of day users agree that opening new areas for dispersed, motorized recreation is a good idea. They evidently like the opportunities they are using now and want to see more areas opened up for this type of recreation. This is in sharp contrast to Wilderness Area users, who want such areas left roadless (Hendee and others 1978).

Although they would like to see new areas opened up with roads, many respondents do not want to see more roads in the areas they were in, a feeling most strongly held by campers in the Taneum-Manastash area. As is true for many other things, people tend to prefer stability. This was particularly true in the Taneum-Manastash, where for many years road building had been minimal. Since this study was conducted, however, many new roads have been constructed there. Future studies will determine what effect they have had on dispersed use (fig. 24).

Paved roads are generally easier to travel and less dusty. Consequently, many managers assume that paving would be good for recreationists. But most users in this study disagree, as they did in a study reported by Lucas in 1964. Only about one-third of the campers and day users think paving is a good idea; paving was most strongly rejected in the Taneum-Manastash area. They may recognize, and suggested by the ROS, that paving changes the nature of opportunity and subsequent recreation use. Paved roads may not be necessary to enhance the recreation experience that users seek in dispersed, roaded areas.

Table 30—Users' attitudes about road management

(In percent)

Questionnaire statement and user group	Response			Total	Statistical summary
	Disagree	Neutral	Agree		
Opening more areas for dispersed road recreation is a good reason for building roads into undeveloped, roadless lands:					
Campers (N=885) 1/	33	14	53	100	χ^2=42.16; p ≤ 0.001;
Day users (N=1,217)	46	15	39	100	γ=-0.25
More roads should be constructed in this area:					
Campers (N=878)	65	24	11	100	χ^2=1.72; p ≤ 0.42;
Day users (N=1,194)	63	24	13	100	not significant
Paving a few main forest roads for dispersed recreation would be a good policy:					
Campers (N=891)	54	15	31	100	χ^2=6.32; p ≤ 0.04;
Day users (N=1,228)	48	16	36	100	γ=0.09
It is alright to close some roads for management purposes such as:					
A. Road maintenance or repair work:					
Campers (N=875)	9	10	81	100	χ^2=1.13; p ≤ 0.43;
Day users (N=1,211)	7	10	81	100	not significant
B. To protect sensitive wildlife:					
Campers (N=870)	14	13	73	100	χ^2=19.96; p ≤ 0.001;
Day users (N=1,221)	9	10	81	100	γ=0.24
C. To improve hunting quality:					
Campers (N=871)	28	15	57	100	χ^2=8.78; p ≤ 0.01;
Day users (N=1,212)	26	20	54	100	γ=0.02
D. To reduce fire hazard:					
Campers (N=880)	9	11	80	100	χ^2=7.76; p ≤ 0.02;
Day users (N=1,215)	6	9	85	100	γ=0.17
E. To conserve limited road maintenance money:					
Campers (N=863)	39	28	33	100	χ^2=13.27; p ≤ 0.001;
Day users (N=1,199)	32	29	39	100	γ=0.14

1/ Numbers in parentheses indicate the number of users who responded.

Figure 24.—Most forest roads are an artifact of timber management. About half the users want new roads opened for dispersed recreation in other areas but want no more built in the currently used areas.

Roads are often closed permanently or temporarily for a variety of purposes. Very often such closures are violated by recreationists who ignore the closure for one reason or another and go around or through gates. We asked respondents to indicate whether or not they agree that closures were alright for road maintenance or repair, to protect wildlife, to improve hunting quality, to reduce fire hazards, and/or to conserve limited maintenance money. These data indicate that, with the exception of hunting and conserving money, closures were acceptable to a large majority. The exception regarding hunting may result from not everyone being a hunter or disapproving of hunting per se and, therefore, of closures to improve hunting. Road closures because of limited budgets found less support than road closure for other reasons.

Table 31—Users' opinions about the impact of logging on dispersed, roaded areas

(In percent)

Questionnaire statement and user group	Response			Total	Statistical summary
	Disagree	Neutral	Agree		
The impact of logging on the landscape detracts from my enjoyment of dispersed road recreation areas:					
Campers (N=883) 1/	30	20	50	100	χ^2=4.47; p ≤ 0.11;
Day users (N=1,230)	26	21	53	100	not significant
This dispersed road recreation has been too heavily roaded and logged:					
Campers (N=878)	41	25	34	100	χ^2=36.10; p ≤ 0.001;
Day users (N=1,205)	30	35	35	100	γ=0.12
The size of clearcuttings that are alright in dispersed roaded areas are:					
A. Large					
Campers (N=861)	69	18	13	100	χ^2=0.0; p ≤ 0.999;
Day users (N=1,178)	69	18	13	100	not significant
B. Small					
Campers (N=877)	17	20	63	100	χ^2=5.87; p ≤ 0.05;
Day users (N=1,210)	21	20	59	100	γ=-0.09
Clearcut logging areas should be hidden from roadside view:					
Campers (N=872)	27	26	47	100	χ^2=0.16; p ≤ 0.92;
Day users (N=1,204)	27	25	48	100	not significant

1/ Numbers in parentheses indicate the number of users who responded.

Impact of logging on recreation.—Dispersed recreation in these and other areas has been occurring in conjunction with timber management for many years. Because this kind of recreation has largely been possible only because of timber management programs and the resulting roads, we question whether people would get more from this type of recreation if roads were built specifically for recreation without evidence of logging. Nearly half the campers and day users agree, in general, that logging detracts from their enjoyment (table 31). There was a large proportion of neutral responses, and 30 percent of the campers and 26 percent of day users disagreed. So half the respondents are not bothered by logging, in general, which is in sharp contrast to the opinion of Wilderness Area users (Hendee and others 1978).

When users were asked whether they thought the area they were in was too heavily logged, about one-third of the respondents agreed. Campers disagreed more than day users, but again there was a large neutral response. With no distinct answer to this or the preceding question, it appears that for many at least, logging is consistent and acceptable for the people presently using the areas. What cannot be determined is how many people like the types of opportunities roaded areas provide but are annoyed enough by the logging to stay away. They would not visit the areas we studied and, consequently, would not be included in our sample.

Clearcut logging is a common silvicultural treatment in each of the study areas. Clearcuttings vary in size and distance from frequently used campsites. When we asked users to indicate if "large" and "small" clearcuttings were acceptable, they strongly rejected large clearcuttings but agreed that small ones were alright. We made no attempt to determine what size users consider large and small; it was only important to ascertain if users differentiate between sizes at all.

Visitors to the three study areas were also asked if clearcuttings should be hidden from roadside view. About half the respondents felt that such areas should be hidden, one-fourth did not think hiding them was necessary, and another fourth did not express an opinion. Campers in the upper Clackamas area were most likely to support hiding clearcuttings, perhaps because they felt the logged areas were more visible from the highway running through the area.

To gain further insight about this issue, we conducted informal conversations with some users in the Taneum-Manastash area during 1977. Here we attempted to determine how people felt about potential effects on their favorite dispersed campsite because of logging. These discussions indicated that about half the people we contacted felt strongly that the campsites were very important to them—there were no equally good sites should theirs be destroyed, and campsites adjacent to "greened-up" clearcut areas were not as good as sites where adjacent trees have not been removed. Most of the people preferred sites that are relatively natural in appearance (no logging evident).

Although these informal contacts may not represent the views of all users, they do help make sense of the findings from the survey. Several conclusions are apparent:

1. Some users do distinguish between the size of acceptable clearcuttings; smaller is better. But many do not find logging objectional per se.

2. Some users distinguish between the areas in general and sites in particular with regard to acceptable management practices. At the macrolevel (area-wide), logging (and clearcuttings) are acceptable; at the microlevel (site), naturalness is important, further indicating that the sites have high recreation values even in heavily logged areas.

These findings are consistent with the ROS framework in which the acceptability of other resource use varies by opportunity class (Clark and Stankey 1979b). That is, while people preferring primitive types of recreation settings would not accept logging under any circumstance (Hendee and others 1978), people preferring dispersed, roaded settings will either accept or reject such use, depending on the nature and extent of the logging (fig. 25).

Grazing.—Of the areas studied, the Taneum-Manastash is the only one where cattle grazing occurs. The practice is fairly widespread, and cattle are often found along roads and at campsites. After users were asked if grazing is acceptable, it was interesting to find that Taneum-Manastash users were more likely to agree than were people from other areas,

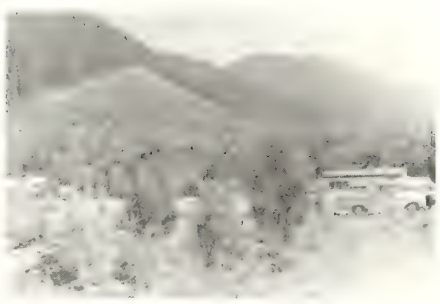

Figure 25.—Logging appears consistent and acceptable to many people presently using dispersed, roaded areas. Most agree, however, that small clearcuttings are better than large ones.

perhaps because they were accustomed to the practice. But we cannot be certain because we do not know if users in the other study areas have visited nonstudy areas where cattle were present (table 32). For many users in our study, grazing is an acceptable practice in areas they use for recreation.

Motorcycles.—Many motorcycles in dispersed recreation areas are not street legal; that is, they are not licensed, do not have safety equipment (lights, mirrors, etc.), and are operated by underage drivers. We asked respondents whether cycles should be legal on forest roads and on trails. Results varied by area. In general, respondents in all areas were more likely to agree to street-legal requirements on roads rather than on trails and skid roads (table 33). Greatest agreement was in the upper Clackamas area where motorcycles of any kind are less common than in other areas. In the other two areas, distinct differences are obvious between campers and day users. Campers (who more frequently have motorcycles) generally reject street legal requirements more often than day users (fig. 26).

Table 32—User's attitudes toward sheep or cattle grazing in dispersed, roaded areas[1/]

(In percent)

Questionnaire statement and response	Campers	Day users
Grazing by sheep or cattle is alright in dispersed road recreation areas:		
A. Disagree	28	27
B. Neutral	16	22
C. Agree	56	51
Total	100	100
Statistical summary	$\chi^2=11.98$; $p \leq 0.003$	$\gamma=0.06$

1/ Based on the number of users who responded: campers 870; day users 1,208.

Table 33—User's attitudes toward requiring motorcycles in dispersed, roaded areas to be "street legal"

(In percent)

Questionnaire statement and user group	Response: Disagree	Neutral	Agree	Total	Statistical summary
All motorcycles should be "street legal"; that is, cycles should meet all state safety requirements and all drivers should be licensed:					
A. On forest roads:					
Campers (N=881) 1/	39	9	52	100	$\chi^2=86.60$; $p \leq 0.001$;
Day users (N=1,225)	21	10	69	100	$\gamma=0.35$
B. On trails and skid roads:					
Campers (N=876)	52	13	35	100	$\chi^2=88.41$; $p \leq 0.001$;
Day users (N=1,216)	33	12	55	100	$\gamma=0.35$

1/ Number in parentheses indicate the number of users who responded.

Figure 26.—Motorcycles are popular for exploring logging roads. Although opinions varied, many respondents felt street-legal requirements on forest roads were more acceptable than on trails.

Table 34—Users' preferences for methods of fire prevention in dispersed, roaded areas[1]/

(In percent)

Fire prevention procedure	Campers	Day users	Statistical summary
Carry shovel, axe, and bucket	90	87	$Z=1.35$; $p \leq 0.18$; not significant
Prohibit campfires when danger is high	79	88	$Z=-4.08$; $p \leq 0.001$
Fire prevention signs at campsites	82	87	$Z=-2.26$; $p \leq 0.02$
Fire patrols along roads alerting users to fire danger	50	50	$Z=0$; $p \leq 1.00$
Close area when fire danger is high	36	47	$Z=-4.97$; $p \leq 0.001$
Require fire permits	11	22	$Z=-4.95$; $p \leq 0.001$

1/ Based on the number of users who responded: campers 898; day users 1,281.

Fire prevention programs.—Respondents were asked to give their preference for different methods of fire prevention. Their preferences, summarized in table 34 are not necessarily related to effectiveness in the prevention of recreation-caused fires.

For the most part, users tend to be supportive of current practices, with no important differences between day users and campers. Both groups generally favor less restrictive procedures, with the exception that both groups agree that campfires should be prohibited when danger is high. In times of high risk, we observed that use goes down anyway, which may be a behavioral measure of users' concern for fire prevention. Yet, closing the areas or requiring permits are viewed as far less acceptable procedures, responses that could have been expected based on users' opinions of regimentation.

Table 35—Users' opinions about the frequency of ranger patrols in dispersed, roaded areas[1]/

(In percent)

Questionnaire statement and response	Campers	Day users
The frequency of ranger patrols in this dispersed, roaded area should be:		
A. Increased	15	18
B. Same as present	59	41
C. Decreased	3	2
D. Do not know	23	39
Total	100	100
Statistical summary 2/	$\chi^2=81.03$, $p \leq 0.001$, $\gamma=-0.26$	

1/ Based on the number of users who responded: campers 862; day users 1,178.
2/ γ was calculated on all responses except "no opinion."

Table 36—Users' opinions about the presence of entry stations in dispersed, roaded areas[1]/

(In percent)

Questionnaire statement and response	Campers	Day users
There should be an entry station for recreationists to check into and out of this area:		
A. Disagree	49	39
B. Neutral	20	27
C. Agree	31	34
Total	100	100
Statistical summary	$\chi^2=25.48$; $p \leq 0.001$; $\gamma=0.13$	

1/ Based on the number of users who responded: campers 892; day users 1,228.

Presence of agency personnel.—Recreationists in dispersed, roaded areas are often contacted by patrols, primarily to warn them of the fire danger. When we asked users if the amount of patrols should be changed, less than 5 percent said "decrease" (table 35). A substantial number said "don't know," with the majority indicating patrols should be kept at the same level. But people in this study were contacted far more frequently by patrols than is standard because our research staff operated as patrollers and contacted camping parties several times. If respondents mean that patrols should be kept at the same level as during the study (where everyone was contacted at least once), that really means patrols should be increased. In any case, these data imply support for contacts with agency patrols. This study and other studies indicate that Forest Service patrols enjoy a positive image on the part of the public (Hendee and others 1976b, Muth and Clark 1978, Stankey 1973) (fig. 27).

Only the Greenwater area had a formal entry station during the study. Users were stopped there and reminded to be careful with fires. When we asked users in all areas if there should be entry stations, there was substantially more disagreement in the Taneum-Manastash and Clackamas areas (table 36). Lack of experience with entry stations may explain why some people reject them. There was a relatively high proportion of neutral responses in all areas. It would appear that if entry stations were used to communicate information necessary to area users, most people would not object to them. Personnel at such points could also keep records about the visitors, which would aid in area management.

Conclusions

Figure 27.—Forest Service rangers often contact recreationists, primarily to warn them of fire danger. Research indicates these personnel enjoy a positive image in the eyes of the public.

The sample used for the study represents the population that camped overnight or entered one of the study areas for day use during the summer and fall of 1976. The sample does not represent all recreationists using dispersed, roaded areas in Washington and Oregon, nor can it be applied to all of the areas used for dispersed, motorized recreation within the two States. The study does, however, shed light on the characteristics, preferences, and opinions of users of three diverse areas used for dispersed recreation that are similar to other areas in the Pacific Northwest. The overall consistency between responses in the three areas tends to indicate that some common traits exist in the types of areas and users studied.

Our informal observations and contacts with area users since 1977 do not indicate there have been any major changes since the study in the attitudes or preferences of visitors to these areas. We suspect that because of increasing energy costs and increased resource uses in several of the areas that some of the patterns of use may have changed. Research plans are to follow the development of recreational use and resource activities over a long period, including repeating the user survey in future years. The present data provide a baseline to evaluate changes that may occur.

Generalizations can be made about the results from our investigations of recreational use in the three areas under study Although there is some danger of creating inaccurate stereotypes by presenting typical patterns, this summary is provided with the assumption that interested readers will study details of the findings to become sensitive to the diversity inherent in the populations studied.

1. Although we have called this type of recreation "dispersed" recreation, most of the use is generally concentrated in key locations along valley-bottom roads and streams. Use of other (and generally higher) areas is more diffuse with activities occurring mostly during the day. Exceptions occur during hunting season and periods of intensive use. And in some cases, people who want to get away from the relatively "crowded" areas select sites in more out-of-the-way locations.

2. Two apparent user groups exist in the areas studied: campers and day users. Although they share many attitudes, there are some significant differences in preferences and resulting patterns of use.

3. Group camping is the rule. Sites in the three areas studied often can accomodate relatively large parties compared to formal campgrounds. Intra-party socialization is an important part of dispersed, motorized recreation.

4. Not only do the users in the sample prefer the types of areas we found them in, but they most often use them as well. Lack of other, more desirable areas was not a reason they visited these locations, as has been suggested. Furthermore, the sample indicated that while their use of other types of settings (developed areas, for example) would remain about the same in the future, they would increase their use of dispersed, roaded areas.

5. There are several major reasons why people like dispersed, roaded areas: privacy from other people not in their party, lack of development, freedom, and the fact that camping in such areas is "their style." They do not like developed recreation settings because there are too many people and the sites are too developed.

Other major attractions are: viewing wildlife, getting away from others, ability to alter the sites to accommodate their needs, lack of regimentation and control, exploring little-used roads, lack of fees, and engaging in activities not allowed or appropriate elsewhere.

6. Most of the users learn about the areas through informal means (family or friends), and by exploring the roads; few learn from information supplied by agencies.

7. A high proportion are very familiar with the areas: they have been coming to the study site for an average of more than 7 years and most have favorite sites to which they usually return. Visitors are from nearby towns or metropolitan areas; few people travel long distances (more than 2 or 3 hours) to reach the areas.

8. Users are specific in site selection. Water, trees, level area, and a private site far away from people not in their party are characteristics they seek.

9. While at the sites, visitors engage in a variety of activities. In fact, all of the 39 activities listed had participants in each of the three study areas. Each area did have some activities which differentiated it from the other areas, but variety was the rule in all of them.

10. With a few exceptions, additional facilities and conveniences are generally not desired in any of the areas. Many users prefer to have some garbage cans, toilets, or water supplies but other data in the survey and conversation with users indicate that lack of facilities is acceptable. Some people expressed their concern that such "improvements" might attract other people, thereby increasing the competition for available sites.

11. In general, visitors of the three areas do not perceive many problems: litter and garbage, fires, noise, vandalism, and theft. This perception contrasts concerns expressed by managers in a companion study (Downing and Clark 1979, Downing and Moutsinas 1978). Users do want the Forest Service to alert them to hazards that might be present.

12. Users are split in their opinions about potential threats of human waste to their health and enjoyment. Lack of knowledge about potential hazards in drinking water from nearby streams and appropriate waste disposal methods is evident.

13. Opinions are divided about the desirability of new roads that would increase opportunities for dispersed, motorized recreation. Users indicate that opening new areas for such recreation is a good reason for building new roads, but they do not want more roads in the areas they visit.

14. Users do not want roads to be paved. Road access is obviously important, but paving evidently represents an unnecessary and perhaps detracting change for many of the recreationists.

15. Road closures are strongly supported for maintenance, wildlife protection, and reducing fire hazard but not for improving hunting quality or conserving limited maintenance money.

16. Users support all but the most restrictive fire prevention procedures. Signs (both at camps and along roads); fire patrols stopping at camps; prohibiting campfires when fire danger is high; and requiring axe, bucket, and shovel are acceptable to most users. Opinions are mixed about closing areas and managing entry stations. A few users would accept a requirement for a campfire permit.

17. Results of the survey plus our observations for more than 7 years indicate that for most of these users, other resource management practices are compatible with recreation. In fact, almost all the use in these areas is dependent upon logging and associated roads. Unlike Wilderness Area users, visitors to the dispersed, roaded areas studied do not object to logging (or grazing in one of the areas where it is common) per se. Although the size of clearcuttings and their location relative to roads and camp sites are important, dispersed-area recreationists do not reject logging and clearcuttings in their area as might Wilderness Area users.

18. Finally, users express strong support for the presence of agency personnel, ranger patrols specifically. The image created by the seasonal personnel who usually fill such positions is highly favorable, a view that can facilitate management of such areas in the future.

Nationally there are many opportunities for the type of recreation found in these three areas. For example, the USDA Forest Service and the U.S. Department of the Interior, Bureau of Land Management both have millions of acres of wildlands open to motorized vehicles, with a network of roads extending several hundred thousand miles. As part of the Forest Service recreation program, dispersed forms of ourdoor recreation such as those described in this paper will be emphasized in the future (USDA Forest Service 1977).

The three areas we studied are different in terms of the recreation opportunities they provide in comparison to other opportunities along the Recreation Opportunity Spectrum (ROS). In contrast to developed, intensively used campgrounds found at the modern-urban end of the ROS (Clark and Stankey 1979b) these dispersed, roaded areas feature more rustic settings where formal facilities are uncommon, recreation use is less concentrated, and far fewer regimenting influences exist. Compared to Wilderness Areas and roadless backcountry on the other end of the ROS, dispersed, roaded areas are accessible by motorized vehicles and allow a wide variety of both motorized and nonmotorized recreation activities along the road system.

Visitors to the three areas seem to be different compared to users of modern and/or primitive areas. The results of this study clearly demonstrate that they choose to go to such areas because of the attractions provided there. As is suggested by the ROS framework, these users predominantly like the roaded access, yet most find unpaved roads acceptable; they enjoy the relatively low level of use and like sites isolated from others; they appreciate the self-regulating nature of these areas where they are free to do whatever they want and alter campsites to suit their objectives; and while generally accepting logging (and clearcuttings) to some degree, they seek naturalness and want favorite sites protected.

Although each of the three areas is different in terms of physical characteristics that increase the occurrence of certain activities, there also is a great deal of similarity. These areas are representative of a type of setting somewhere in the middle of the ROS, yet diversity and variety in terms of physical attributes and resulting activities is found both between the areas as well as within any one area. The goal of management should be to enhance this variety and diversity in ways consistent with ROS principles. It is not important that each area, or roads within a particular area, be managed in exactly the same fashion; it is only necessary that management recognize there is a range of appropriate conditions acceptable to users in dispersed, roaded areas. These areas are valuable because of a special combination and range of manageable conditions that easily can be enhanced—or that just as easily can be destroyed if explicit recreation management goals are not clearly stated in advance.

The recreation use investigated in this study was possible only because of the road systems developed for other resource programs, primarily logging. The results indicate that resource uses such

as timber are generally consistent with the values and goals of the recreationists who use the areas. These users do not reject such practices as might people who prefer the more primitive styles of outdoor recreation. Consequently, it seems important that planners and managers examine multiple use programs to see where current practices might be modified to maximize the benefits of dispersed, motorized recreation while minimizing conflicts. Road design and timber sale layout might be altered in such ways to increase the ability of users of these areas to find the kind of setting most to their liking. Research seems to indicate that multiple use of the same lands for recreation and other resource programs is not only practical in these areas, but desired by a segment of the public as well.

But the observations and findings from this research should not be construed as a reason or excuse to log previously unlogged areas. Rather, the results discussed indicate that when a decision is made to harvest timber for commodity values, it may also be possible to provide some quality recreation opportunities in such areas. There may also be situations, however, where silvicultural alternatives should be considered expressly for recreation, rather than production of commodities. Management objectives will guide such decisions.

Because a policy of National Forest management is to place increased emphasis on dispersed forms of outdoor recreation, it is important that recreation sites used frequently, or those that have special qualities, deserve consideration in land use planning. It seems particularly important that all functional areas of resource management (for example, fire, timber management, engineering, recreation, and others) utilize such information in their programs so that recreation sites established by users are not lost inadvertently. The fact that so many people have been coming to these areas frequently for many years indicates that these locations have some special appeal for them. Future management programs must consider the value recreationists place on these attractions and the noneconomic as well as economic costs associated with altering those settings.

Of primary concern to managers and recreationists alike should be the identification and protection of attractive sites for dispersed, motorized recreation. The campsites seem to be particularly important and are often destroyed unknowingly as part of other resource activities. By identifying where sites are, and determining which ones have frequent use and/or special appeal, managers are better able to insure their use in the future. But it is clear that areas like those under study will always be in a constant state of change. This seems particularly true in forested areas with mixed land ownership and with multiple-use objectives. Undoubtedly some prime locations will be lost as resource programs evolve. For example, Code-A-Site inventories conducted in the Greenwater area in 1975 and then again in 1978 indicate that 57 percent of the original sites no longer existed: 37 percent were destroyed by management and 17 percent through flooding. With knowledge about what are the important recreation opportunities in an area, such changes can be made as a part of a planned effort rather than inadvertently because of oversight. And with information about what users define as being of value to them, planners are better able to identify new locations in the inventory and planning processes before presently roadless areas are opened for motorized entry.

Results of this study clearly document the self-regulating nature of recreation in these areas. These users have found areas to their liking and, by exploring similar places, may find additional appealing sites. The role of visitor information services seems important in facilitating this process so that they are able to find their brand of outdoor recreation. At present, little information exists through formal channels about the nature of the recreation opportunities on lands open to the public. It would seem helpful to map not only existing transportation systems (roads and trails), as is currently done by several agencies on maps available to the public, but also to identify the type of recreation settings they can expect (modern-urban to primitive, in ROS terminology). Such delineation is presently being done as part of a nationwide recreation opportunity inventory by the Forest Service, and this information, if available to the public, would aid users with decisions about where to go to meet their expectations. Any public information system should also include knowledge about what is acceptable behavior in these areas. The "no trace camping" ethic endorsed by the USDA Forest Service in primitive areas, for example, might be expanded to dispersed, roaded areas as well.

The role of the ranger seems particularly important in providing such information. Results of this study show the wide acceptance of contacts by agency personnel. Other studies on litter control (Clark 1976, Muth and Clark 1978) also show a generally positive acceptance of uniformed personnel. Our observations indicate that such contacts seem to work best when information is transmitted about how a problem can be solved rather than an admonishment to "be careful." For example, a major concern in the areas studied was fire; most ranger patrols were in the areas primarily to warn users about fire dangers. In some instances sites were "fireproofed"; that is, a ranger moved any hazardous material and built an appropriate firering in the absence of recreationists. Often, however, when users arrived they would alter the site (a major appeal of these areas) and move the firering to a place in keeping with their goals. But the new location might not be appropriate from a fire prevention perspective. Consequently, we recommend that whenever possible rangers show the campers, children in particular, how to build a safe firering. With this new knowledge they are more likely to alter sites in appropriate ways in the future.

What the future holds for dispersed, motorized recreation is unclear. Energy shortages and increasing gasoline prices make it difficult to predict how much of this type of recreation will be desired or possible in the future. Users in this study indicate that while they intend to do more of this type of recreation in the future, they will make trips to nearby areas rather than travel long distances. Public lands near metropolitan areas, like the three we studied, therefore, might see increases in the future. And, we might see a shift away from large vehicles and trailers to more economical and fuel-effecient RV's. If the recreation opportunities studied are as unique and appealing as this study seems to indicate, this use is likely to continue and even increase into the future. Long-term studies will be necessary to document any changes that might occur.

As a final point, we must emphasize that whether managers are aware of it or not, practices they follow on forest lands open to public use will affect the nature of dispersed recreation opportunities and the enjoyment and experiences of users. Many options exist that will either hinder or facilitate recreation activities, and many of the latter would require little investment of time or money. The key is to make goals and objectives explicit prior to action, a practice requiring that recreation management objectives be integrated and coordinated with other multiple-use objectives prior to resource inventory.

In short, there seems to be a great potential for increasing the amount and quality of dispersed recreation opportunities in roaded forests. Only the sensitivity of managers and their creativity in finding ways to accommodate forest visitors will maximize such options. As presently roadless areas are opened for resource development, or roaded areas are re-entered, there is the opportunity to provide recreation values in conjunction with primary extractive uses at apparently little cost in terms of budget and time. This would seem to be particularly important in forests near communities so that the public can have energy-efficient access to a range of desirable opportunities. The alternative may lead to less-than-optimum conditions for both the manager and visitor, resulting in displacement of use from one area to another and the unnecessary loss of prime recreation habitat.

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The value of roaded, multiple use areas as recreation sites in three National Forests of the Pacific Northwest. Res. Pap. PNW-319. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 40 p.

Dispersed recreation along forest roads in generally undeveloped areas is increasing rapidly in the West. To effectively manage this use and integrate it with other forest activities requires information about the preferences, expectations, and opinions of forest visitors and their patterns of recreation use. Results of a 3-year study of campers and day users in three roaded forest areas of Washington and Oregon suggest this type of area provides opportunities that are very different from those in developed campgrounds and primitive backcountry. Visitors to roaded, forested areas like the generally unpaved road access, the low level of use, and the freedom to alter campsites to suit their objectives. Although this type of recreation is found in conjunction with resource management activities, such as logging and livestock grazing, recreationists do have favorite sites they return to year after year. Such sites may, therefore, warrant some protection. Future management programs must consider the value recreationists place on these sites and area attractions and the noneconomic as well as economic costs associated with altering these settings.

Keywords: Dispersed recreation, recreation (dispersed), recreation use, roads (forest), logging effects, recreation management, multiple use –)recreation, recreationists.

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Lumber Recovery From Insect-Killed Lodgepole Pine in the Northern Rocky Mountains

Marlin E. Plank

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Abstract

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A total of 496 logs from lodgepole pine (*Pinus contorta* Dougl. ex Loud.) trees killed by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) were compared with 189 logs from similar live trees. Logs were processed through a stud mill. In most cases lumber recovery from trees dead 1 to 3 years was the same as that from live trees. Less cubic volume was recovered from trees dead 4 or more years. Recovery tables and curves are shown.

Keywords: Lumber recovery, lumber yield, dead timber, insect damage (-forest products, lodgepole pine, *Pinus contorta,* Rocky Mountain area.

Summary

A sample of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) trees from the Bridger-Teton National Forest in Wyoming and the Targhee National Forest in Idaho that had been killed by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) was processed through a stud mill. Logs from similar live trees were sawn to compare their product recovery with that of logs from the dead trees. Generally, volume recovered from logs of trees dead 1 to 3 years was the same as that recovered from live trees. Less cubic volume was recovered from trees dead 4 or more years.

Average stud grade recovery was 86 percent of the volume in the live sample compared with 73 percent in the dead sample. The value per unit of lumber volume recovered was lower for the dead sample, but there was no clear distinction between values of any of the time-since-death classes in that respect.

Lumber volume recovery is based on long log Scribner scale and on gross cubic scale.

Introduction

In the mid-1970's the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) killed millions of board feet of timber in the Targhee National Forest in Idaho and the Bridger-Teton National Forest in Wyoming. Many dead and dying trees remain from past attacks in lodgepole pine (*Pinus contorta* Dougl. ex Loud.) stands. In western Wyoming and eastern Idaho, estimates of accessible dead lodgepole pine range as high as 1.25 billion board feet, most of which has been killed by the mountain pine beetle. These stands are esthetically unpleasant, management of the lodgepole pine resource is difficult, and the huge amounts of fuel are a fire hazard.

In 1977, the USDA Forest Service (Rocky Mountain and Intermountain Regions and the Timber Quality Research unit of the Pacific Northwest Forest and Range Experiment Station) and the forest products industry cooperated in a study to: (1) determine the lumber recovery of a sample of beetle-killed lodgepole pine trees, (2) compare the lumber recovery and value of beetle-killed lodgepole pine with a similar sample of live trees, and (3) evaluate time-since-death classes of the beetle-killed trees to determine their relationship to recovery and value.

Field Procedures

Timber Sample

Timber was sampled from the Bridger-Teton and Targhee National Forests, an area representative of the range in size and quality of lodgepole pine in western Wyoming and eastern Idaho. Local foresters familiar with the lodgepole pine resource participated in selecting sample areas.

The three areas selected contained sizes of sawtimber trees normally encountered. The areas also contained trees that had been attacked by the mountain pine beetle at different times during the 11 years prior to the study. Trees on each area were selected to insure that all diameter classes were included in the sample. A total of 448 trees were designated on the three areas; when study trees were selected they were placed into classes based on estimated time since death. These classes were determined by the color of the needles and on the percentages of needles, small branches, twigs, and bark retained. Three classes of dead trees were defined, based on these estimates: dead 1 to 3 years, dead 4 to 7 years, and dead longer than 7 years.

Table 1 shows the range of diameters and heights and the average diameter and height for the sample trees by area. Analyses were run collectively on all areas.

Table 1—Diameters and heights of sample lodgepole pine trees, by area

Area and class of trees	Range of diameters	Average diameter	Range of heights	Average height
	- - - - Inches - - - -		- - - - Feet - - - -	
Area 1:				
Live	7.2-13.9	10.1	67- 86	78
Dead	8.0-16.4	11.4	58- 89	74
Area 2:				
Live	8.0-17.2	13.0	61- 95	78
Dead	9.1-22.3	13.6	60-102	80
Area 3:				
Live	7.0-13.3	9.6	52- 84	68
Dead	8.4-20.9	12.9	44-101	70

Felling and Identification

Study trees were felled and bucked following normal industry practice. Diameter and length of each bucked log were recorded along with tree height for each sample tree. Each log was tagged to identify tree number and log within the tree.

Scaling

When all logs had been delivered to the mill yard, they were rolled out and scaled. Net scale of all dead logs was determined according to the National Forest Log Scaling Handbook (USDA Forest Service 1973) rules; however, no deduction was made for drying or weather checks. This estimate should approximate the net scale of live logs for realistic recovery percentages. Reasons for each scale deduction were documented. Cubic volumes based on Scribner diameters and Smalian's formula were also determined for all logs. After the logs were bucked into 8-foot lengths, they were again scaled by Scribner log rule.

Lumber Manufacturing

Each log was sawn to recover its optimum value through manufacture of the mill's usual lumber items. About 94 percent of the total volume is made up of studs. The major equipment in the mill included a band head saw, a four-saw scragg, double arbor edger, and a hula trim saw. There was a reclaim area where lumber could be ripped, trimmed, or resawn. An automatic stacker was used for 8-foot 2x4's.

A Western Wood Products Association grading inspector either graded or supervised the grading of lumber on the planer chain. Lumber was graded under the Western Wood Products Association (1977), "Grading Rules for Western Lumber." Lumber volumes were based on a surfaced-dry shipping tally.

Cubic Calculations

The gross cubic volume of logs was computed by Bruce's (1970) formula for butt logs and Smalian's formula for all other logs.

Bruce's formula:

$$\text{Volume} = 0.0054545\ (0.3677\ D_s^2) + 0.6688\ (D_s \times D_L) - 0.000148\ (D_s \times D_L)L;$$

Smalian's formula:

$$\text{Volume} = 0.002727\ (D_s^2 \times D_L^2)L;$$

where:
D_s is the log scaling diameter (inches) of the small end,
D_L is the log scaling diameter (inches) of the large end, and
L is the log scaling length (feet).

The cubic-foot volumes of lumber were based on measurements of surfaced-dry lumber. The cubic foot volumes of sawdust were calculated from the average saw-kerf thickness and the rough-green surface area of the lumber from each log. Shrinkage and planer shavings were determined by subtracting the volume of surfaced-dry lumber from the volume of rough-green lumber. The residue volume was the gross log volume minus volumes of lumber, sawdust, shrinkage, and planer shavings. Thus, the residue volume includes a small amount of sawdust from the production of slabs, edgings, trim ends, and some defect.

Analysis

Model Selection

Five regression models were compared. Volume and value were expressed as functions of different combinations of the independent variables D, 1/D, $1/D^2$. The final model for each response variable was selected based on the statistics of the regression ($s_{y \cdot x}$, the standard deviation about regression, and R^2, the coefficient of determination), each coefficient being significant ($P \leq 0.05$), and on information obtained from fitting these models in previous studies.

Results

Dependent variables used were:

1. Cubic recovery percent (CR%).[1/]
2. Lumber recovery factor (LRF).
3. Recovery ratio.
4. Dollars per thousand board feet of lumber tally ($/MLT).
5. Dollars per hundred cubic feet of gross log volume ($/CCF).

From the model that best fit all the response variables,

$(y = b_0 + b_1(d) + b_2(1/d) + b_3(1/d^2)$,

where d = diameter,

covariance analysis was used to compare the three classes of dead material. If differences occurred, the individual classes were compared to isolate the differences. Classes not significantly different were combined and compared with live material.

The analysis indicated a significant difference ($P \leq 0.05$) among the three classes, except in $/MLT. Further analysis of the other four response variables indicated no difference between the two older groups of logs from dead trees, so they were combined. Next, the 1- to 3-year-dead group and the combined group were compared and found to be significantly different ($P \leq 0.05$). The final comparison was between the logs from trees dead 1 to 3 years and the logs from live trees. This analysis showed a significant difference, but differences in the curves did not appear to be practically important relative to the variation in the data. The γ_m criterion (Draper and Smith 1981) was used to determine if the significant difference between the logs from trees dead 1 to 3 years and logs from live trees was of practical importance. This criterion requires observed F values at least four times the tabled value for the regression coefficients to be practically useful compared with just statistically significant. By use of this criterion, logs from trees dead 1 to 3 years and logs from live trees were combined for all response variables, except $/MLT. Separate means for the logs from the live sample and logs from all the dead samples were retained since there was no significant relationship of $/MLT to diameter.

Tables 2 and 3 present summaries of log scale, lumber tally, and cubic volumes obtained from the study logs. Lumber yields are shown in both board feet and cubic feet of surfaced-dry lumber (shipping tally volume). The cubic-foot volume of the logs, lumber, sawdust, shrinkage, and planer shavings and residues calculated by 1-inch diameter classes is also shown.

[1/] Cubic recovery percent = rough-green cubic-foot lumber volume divided by gross cubic foot of log volume times 100.

Table 2—Log scale, lumber tally, and cubic volumes by scaling diameter for logs from live lodgepole pine trees and logs from trees dead 1 to 3 years

Log scaling diameter 1/	Number of logs	Scribner log scale		Lumber tally		Volume 3/					
		Gross	Net	Volume	Recovery ratio 2/	Log	Surfaced-dry lumber	Lumber recovery 4/	Green sawdust	Shrinkage and planer shavings	Chippable volume
Inches		Board feet			Percent	Cubic feet		Percent			
5	43	1,795	1,725	2,698	156	373.07	145.65	39	13	11	37
6	114	6,255	6,005	9,008	150	1,267.74	486.86	38	13	11	38
7	72	4,120	3,870	5,036	130	726.15	272.80	38	12	10	41
8	36	1,460	1,340	1,908	142	333.38	102.31	31	11	9	49
9	38	2,090	1,960	2,656	136	431.69	143.11	33	11	10	46
10	29	2,430	2,330	2,756	118	430.65	147.79	34	11	9	46
11	15	2,090	1,940	2,644	136	345.69	141.76	41	13	10	36
12	8	1,010	1,010	1,330	132	181.89	71.53	39	13	10	38
13	8	1,790	1,790	2,257	126	293.51	121.42	41	12	10	37
14	4	1,100	1,020	1,401	137	187.28	75.55	40	13	9	37
Total or average	367	24,140	22,990	31,694	138	4,571.05	1,708.78	37	12	10	40

1/ In accordance with National Forest Log Scaling Handbook (USDA Forest Service 1973) rules.
2/ Equals lumber tally volume divided by net log scale times 100.
3/ Lumber volume based on surfaced-dry dimensions. Chippable volume equals gross log volume minus volume of lumber, sawdust, and shrinkage and planer shavings.
4/ Equals cubic lumber volume divided by cubic log volume times 100.

Table 3—Log scale, lumber tally, and cubic volumes by scaling diameter for logs from lodgepole pine trees dead 4 years or more

Log scaling diameter 1/	Number of logs	Scribner log scale		Lumber tally		Volume 3/					
		Gross	Net	Volume	Recovery ratio 2/	Log	Surfaced-dry lumber	Lumber recovery 4/	Green sawdust	Shrinkage and planer shavings	Chippable volume
Inches		Board feet			Percent	Cubic feet		Percent			
5	7	560	530	694	131	96.75	37.49	39	13	10	38
6	67	3,215	3,035	4,032	133	676.96	218.11	32	10	8	49
7	69	4,270	4,120	4,975	121	786.12	268.43	34	11	9	46
8	44	2,360	2,230	2,933	132	512.34	158.24	31	9	9	51
9	36	2,690	2,580	3,105	120	518.63	167.47	32	10	8	49
10	39	3,520	3,230	3,809	118	640.99	204.66	32	10	8	50
11	21	2,820	2,650	3,224	122	506.97	174.44	34	10	8	47
12	13	2,020	1,860	2,344	126	351.10	127.03	35	8	9	47
13	11	2,010	1,820	2,360	130	332.37	127.27	38	11	9	42
14	4	920	860	1,000	116	148.96	53.95	36	9	9	46
15	4	1,130	1,090	1,277	117	182.06	69.11	38	9	8	45
16	2	710	710	819	115	120.58	44.23	37	7	8	48
17	1	410	390	548	141	64.84	29.72	46	15	10	29
Total or average	318	26,635	25,105	31,120	124	4,938.67	1,680.15	34	10	9	47

1/ In accordance with National Forest Log Scaling Handbook (USDA Forest Service 1973) rules.
2/ Equals lumber tally volume divided by net log scale times 100.
3/ Lumber volume based on surfaced-dry dimensions. Chippable volume equals gross log volume minus volume of lumber, sawdust, and shrinkage and planer shavings.
4/ Equals cubic lumber volume divided by cubic log volume times 100.

Cubic Recovery

Percentage of cubic log volume produced as rough green lumber is plotted over diameter for all logs in figure 1 for the two classes of logs. The general trend is a slight increase in recovery as diameter increases. Average recovery of cubic volume in percent for the logs from live trees and logs from trees dead 1 to 3 years was 47 percent, and for logs from trees dead more than 3 years, 44 percent.

This cubic recovery differs from that observed from other studies in that generally curves from other studies start out with low recovery in the lower diameters, rise as diameter increases, and then flatten. The explanation for this curve to drop and then rise again is probably that most logs were processed on a 4-saw scragg where the major product was 4-inch cants. Apparently in the 6- to 7-inch logs, the cant size was not increased relative to the increase in log volume, so a greater proportion of the logs of that size was chipped.

Lumber Recovery Factor

Figure 2 presents the relationship between lumber recovery factor (LRF[2/] and diameter. The shapes of the curves are similar to the curves for recovery of cubic volume. The mean LRF for the logs from live trees and from trees dead 1 to 3 years was 6.3, whereas that for logs from trees dead 4 or more years was 5.6.

Recovery Ratio[3/]

Figure 3 shows the relationship between recovery ratio (overrun) and diameter. Recovery ratio for the logs from live trees and logs from trees dead 1 to 3 years is high in the small diameters but decreases as diameter increases to about 8 inches where it levels off. The variance in recovery of small diameters was much greater than that of larger diameters, but no techniques to overcome this problem were explored. There was no significant relationship for the logs from trees dead 4 years or more where the average recovery was 124 percent.

Recovery ratio of the logs from dead trees was analyzed two ways; when a deduction for check was included in the total defect and when it was excluded. When a deduction for checks was included, many of the logs were culled and recovery ratios were as high as 600 percent. Because it appeared that excluding the deduction for checks on the logs from dead trees would give net scales that approximated logs from live trees, a decision was made to exclude the deduction for checks.

[2/] Lumber recovery factor = board feet of lumber tally per cubic foot of gross log volume.

[3/] Recovery ratio is overrun plus 100 percent.

Figure 1.—Percentage of cubic volume of lodgepole pine logs produced as rough-green lumber, by log diameter:

Logs from live trees and logs from trees dead 1 to 3 years—
Cubic recovery (percent)
= -99.66 + 7.32(d) + 817.95(1/d) - 1,308.07(1/d²).
Coefficient of determination = 0.057.
Standard deviation from regression = 11.3.

Logs from trees dead 4 or more years—
Cubic recovery (percent)
= 119.95 - 1.62(d) - 944.34(1/d) + 3,022.90(1/d²).
Coefficient of determination = 0.059.
Standard deviation from regression = 11.7.

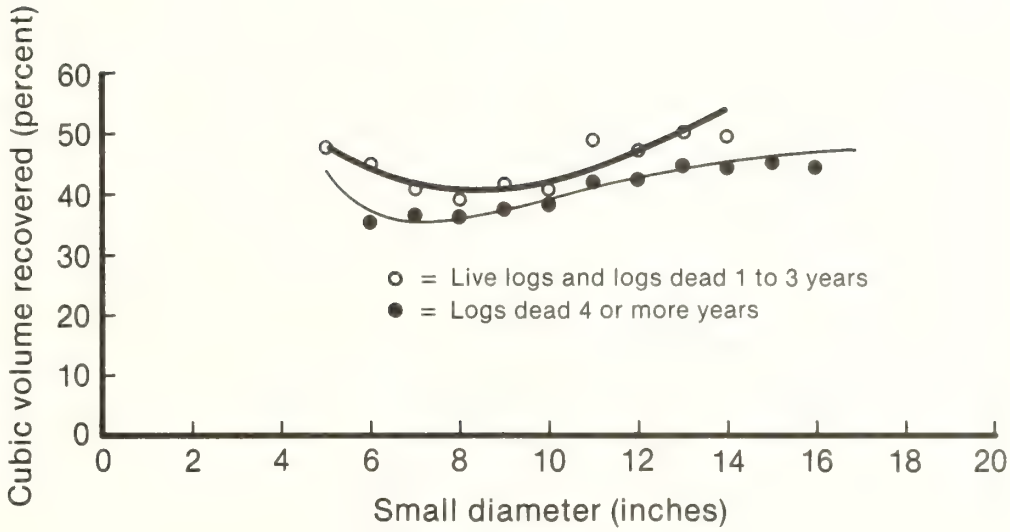


Figure 2.—Lumber recovery factor: Board feet of lumber tally per cubic foot of gross log scale, by diameter:

Logs from live lodgepole pine trees and from trees dead 1 to 3 years—
LRF = 18.27 + 1.257(d) + 142.95(1/d) - 241.27(1/d²).
Coefficient of determination = 0.064.
Standard deviation from regression = 1.69.

Logs from lodgepole pine trees dead 4 years or more—
LRF = 16.76 - 0.18(d) - 136.09(1/d) + 445.70(1/d²).
Coefficient of determination = 0.071.
Standard deviation from regression = 1.85.

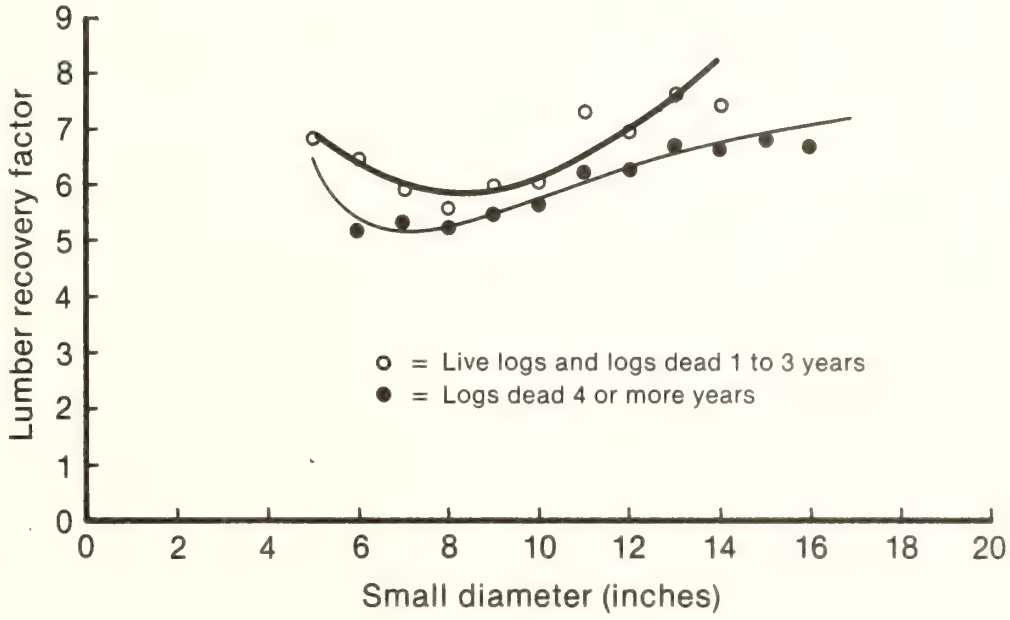
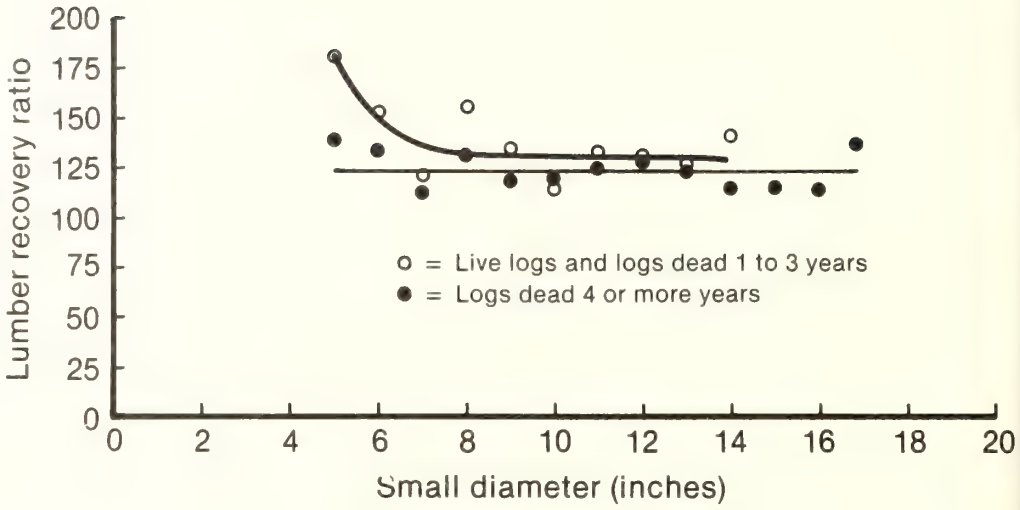


Figure 3.—Lumber recovery ratio from lodgepole pine logs, by diameter:

Logs from live trees and from trees dead 1 to 3 years—
Recovery ratio = 384.18 - 8.12(d) - 2,646.67(1/d) + 9,186.17(1/d²).
Coefficient of determination = 0.113
Standard deviation from regression = 44.8

Logs from trees dead 4 years or more—
Recovery ratio = 124.
Standard error of the mean = 2.2.



Grade Yields

Tables 4-6 show percentage of recovery for each lumber grade by 1-inch diameter class. Grade yield varied by time since death. For the logs from live trees together with the logs from trees dead 1 to 3 years, 79 percent of the total volume was produced as Stud grade; 13 percent, Economy Stud. For logs from trees dead 4 or more years, 73 percent of the total volume was graded Stud and 22 percent Economy Stud.

Value ($/MLT)

The $/MLT relationship to diameter was not statistically significant. There was also no difference in recovery among the dead logs. For this relationship, all the dead logs were grouped together. The average $/MLT for the live logs was $201.51; for the dead logs, $181.48. These relationships are based on 1978 lumber prices (table 7) furnished by the Intermountain Region (Region 4) of the USDA Forest Service. A significant change in price between the lumber grades could change the difference in average values.

Table 4—Lumber grade recovery as a percentage of surfaced-dry lumber tally for logs from live lodgepole pine trees

Log scaling diameter	Number of logs	Lumber tally	Moulding	Common				Stud	Economy Stud
				No. 2 and better	No. 3	No. 4	No. 5		
Inches		Board feet	Percent						
5	21	1,119	0	2.23	6.34	2.50	0	82.04	6.88
6	59	3,920	.43	.74	8.09	2.07	.05	83.37	5.26
7	37	1,901	.58	.47	7.42	1.84	.47	80.69	8.52
8	16	832	2.52	1.80	6.49	2.16	0	82.81	4.21
9	19	1,471	1.56	1.56	5.30	1.90	0	84.84	4.83
10	19	1,869	1.82	.32	3.32	.54	0	89.57	4.44
11	11	1,698	2.89	.88	2.06	.88	0	89.10	4.18
12	2	212	3.77	0	3.77	0	0	87.26	5.19
13	3	942	.96	0	.53	.21	0	94.06	4.25
14	2	610	.98	0	0.82	1.64	0	92.46	4.10
Total or average	189	14,574	1.22	.84	5.32	1.56	.08	85.63	5.36

Table 5—Lumber grade recovery as a percentage of surfaced-dry lumber tally for logs from lodgepole pine trees dead 1 to 3 years

Log scaling diameter	Number of logs	Lumber tally	Common				Stud	Economy Stud
			No. 2 and better	No. 3	No. 4	No. 5		
Inches		Board feet	Percent					
5	22	1,579	0.13	5.13	3.74	0.51	78.21	12.29
6	55	5,088	.04	4.72	3.46	.41	72.66	18.71
7	35	3,135	.06	3.44	2.65	.06	77.19	16.59
8	20	1,076	.19	4.93	6.23	.46	71.10	17.10
9	19	1,185	0.25	4.73	6.08	.51	71.31	17.13
10	10	887	0	1.24	1.92	.56	60.88	35.40
11	4	946	0	.63	1.27	0	72.41	25.69
12	6	1,118	.45	1.34	2.68	0	76.92	18.60
13	5	1,315	0	.84	1.22	.23	72.78	24.94
14	2	791	0	0	.76	0	79.65	19.60
Total or average	178	17,120	.09	3.39	3.14	.29	73.80	19.28

Table 6—Lumber grade recovery as a percentage of surfaced-dry lumber tally for logs from lodgepole pine trees dead 4 years or more

Log scaling diameter	Number of logs	Lumber tally	Common				Stud	Economy Stud
			No. 2 and better	No. 3	No. 4	No. 5		
Inches		Board feet	Percent					
5	7	694	0	3.17	3.89	0.29	61.38	31.27
6	67	4,032	.24	3.22	2.98	.20	71.60	21.75
7	69	4,975	.10	2.91	3.70	.18	71.08	22.03
8	44	2,933	0.34	3.95	3.72	.48	72.93	18.58
9	36	3,105	.39	2.67	3.06	.29	73.88	19.71
10	39	3,809	.24	2.02	2.55	.29	73.64	21.27
11	21	3,224	0.09	1.46	1.99	.19	80.09	16.19
12	13	2,344	0.13	1.24	2.90	.21	72.18	23.34
13	11	2,360	.08	1.23	1.14	.42	68.43	28.69
14	4	1,000	0	.60	3.00	.42	70.30	26.10
15	4	1,277	0	.47	.47	.39	74.94	23.73
16	2	819	0	.37	1.83	0	67.16	30.65
17	1	548	0	0	.91	0	87.77	11.31
Total or average	318	31,120	.17	2.23	2.72	.25	72.84	21.79

Table 7—Average yearly lumber prices for white woods, 1978

Lumber grade	Item			
	1 inch	2 x 4	2 x 6	2 x 8
	Dollars per thousand board feet lumber tally			
Moulding	381.78			
No. 2 and Better Common	381.78			
No. 3 Common	212.73			
No. 4 Common	162.46			
No. 5 Common	91.19			
Standard and Better		219.45		
Utility		167.62		
Economy		89.87	89.87	89.87
Stud		204.64		
Economy Stud		90.45		
No. 2 and Better			207.77	213.92
No. 3			146.26	146.26

Source: Intermountain Region, USDA Forest Service.

Value ($/CCF)

Figure 4 shows the relationship of dollars per hundred cubic feet of gross log volume ($/CCF) to diameter for the two classes of logs.

The $/CCF and $/MLT relationships were expected to exhibit similar trends, but they did not. Although average lumber value ($/MLT) was the same for all logs from dead trees, the LRF was higher for the logs from trees that recently died. This caused the value per unit of log volume ($/CCF) for logs from trees recently dead to be much higher than for logs from trees dead longer. Dollars per unit of log volume is considered the most important single indicator of value.

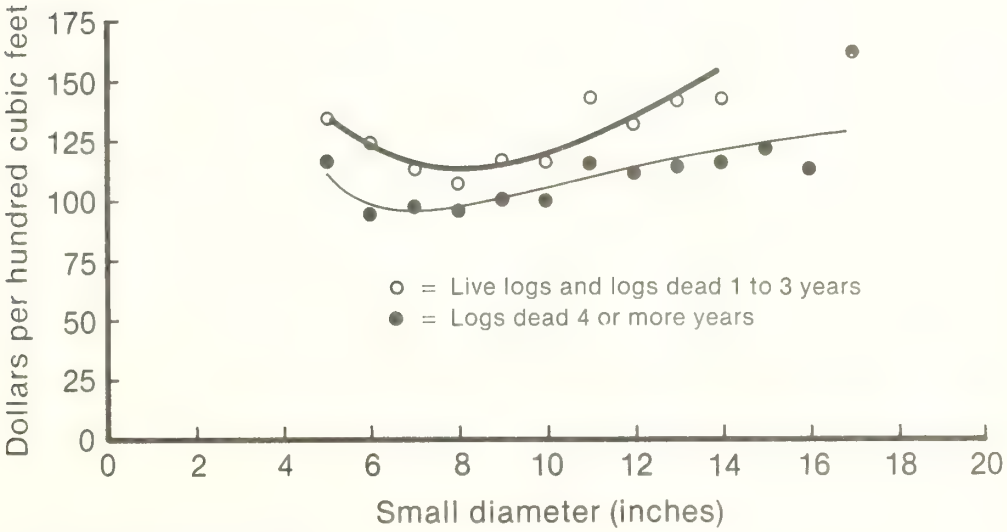


Figure 4.—Dollars per hundred cubic feet of gross log scale over diameter:

Logs from live lodgepole pine trees and from trees dead 1 to 3 years—

$$\$/CCF = -193.52 + 17.77(d) + 1{,}501.31(1/d) - 1{,}487.22(1/d^2).$$

Coefficient of determination = 0.063.

Standard deviation from regression = 33.06.

Logs from lodgepole pine trees dead 4 years or more—

$$\$/CCF = 224.86 - 1.21(d) - 1{,}624.33(1/d) + 5{,}417.63(1/d^2).$$

Coefficient of determination = 0.048.

Standard deviation from regression = 31.89

Conclusions

Overrun for the logs from live trees and the logs from trees dead for 3 years was 44 percent, whereas the logs from trees dead 4 years or more had an average overrun of 24 percent. Because the logs did not have a wide range of diameters, there was not a strong correlation between overrun and diameter, even in the live and 1- to 3-year-dead classes.

Cubic recovery of surfaced-dry lumber by diameter class varied from 35 percent to 56 percent. Comparable figures for rough-green material were 43 to 61 percent. Average cubic recovery was about 10 percent more when it was based on rough-green lumber than when based on surfaced-dry lumber.

Stud recovery for the live sample was 86 percent of the total volume. For all the dead samples combined, it was 73 percent. For lumber grade distribution only, all the dead material could be combined. This is reflected in the $/MLT values where there was no significant difference among time-since-death classes in the sample of dead trees.

This report indicates that for volume recovery only, less lumber was recovered from the older dead material than from the combined samples of logs from recently dead trees and from live trees. This relationship also holds for the value per unit volume of log ($/CCF). For average value of the lumber produced, there was no difference among any of the dead samples; however, there is a clear distinction between the dead and the live samples.

Metric Equivalents

1 inch = 2.540 centimeters
1 foot = 0.305 meter
1 cubic foot = 0.028 cubic meter

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Plank, Marlin E. Lumber recovery from insect-killed lodgepole pine in the northern Rocky Mountains. Res. Pap. PNW-320. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 12 p.

A total of 496 logs from lodgepole pine (*Pinus contorta* Dougl. ex Loud.) trees killed by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) were compared with 189 logs from similar live trees. Logs were processed through a stud mill. In most cases lumber recovery from trees dead 1 to 3 years was the same as that from live trees. Less cubic volume was recovered from trees dead 4 or more years. Recovery tables and curves are shown.

Keywords: Lumber recovery, lumber yield, dead timber, insect damage (-forest products, lodgepole pine, *Pinus contorta*, Rocky Mountain area.

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Estimators and Characteristics of Logging Residue in Montana

James O. Howard and Carl E. Fiedler

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Abstract

Howard, James O.; Fiedler, Carl E. Estimators and characteristics of logging residue in Montana. Res. Pap. PNW-321. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 29 p.

Ratios are presented for estimating volume and characteristics of logging residue in Montana. They relate cubic-foot volume of residue to thousand board feet of timber harvested and to acres harvested. Tables show gross and net volume of residue, with and without bark, by diameter and length classes; by number of pieces per acre; by percent soundness; by product potential; and by degree of slope and distance to roads.

Keywords: Residue estimation, residue measurements, slash, volume estimation, slash utilization, residue management, Montana.

Summary

Interest in utilizing logging residue has resulted in an increasing number of assessments of the feasibility of using the residue to produce energy or conventional wood products at specific facilities. These site-specific analyses have revealed the need for a data base that permits a more flexible method of obtaining information on the volume and characteristics of residue.

This study developed ratios that can be used to estimate the volume of logging residue, based on volume of timber harvested or on number of acres harvested, for any specific location in Montana. It also provides data on the characteristics of logging residue that affect residue utilization for energy or other products.

The information is based on measurements of logging residue on 120 cutover areas. Sample areas were allocated to four strata (public land clearcuts, public land partial cuts, private land, and lodgepole pine). Results are shown by strata. Tables show gross and net (chippable) volume, with and without bark. An example of how to apply the data is provided.

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1 **Study Design**
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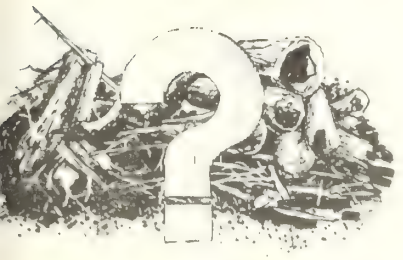
Introduction



Energy shortages during the past decade have focused attention on finding alternative sources of fuel. Sources considered to be renewable have been given special emphasis. Of these, woody biomass has greater near-term potential than most others. Wood residue associated with timber harvest has drawn special attention as a major source of wood fiber. In the northern Rocky Mountains logging residue[1] that can be recovered in conjunction with conventional timber harvest operations appears to have the greatest potential for short-term utilization, both for energy and conventional wood products (Keegan 1981).

Assessing the feasibility of utilizing residue at specific locations requires reliable estimates of residue volume and characteristics for uniquely defined supply zones.

A recent study provides analytical tools and data for site-specific analysis of logging residue in Washington, Oregon, and Idaho (Howard 1981a, 1981b). Equivalent information has not been available for Montana.

A number of studies in Montana have developed information on the down, dead, and cull components of timber stands prior to harvest (Benson and Schlieter 1980, Brown and See 1981, Keegan 1981). Although these sources provide valuable information for forest residue conditions, they are not adequate for estimating volume or describing characteristics of logging residue within defined supply zones.

[1] See Glossary for terms used in this report.

This report presents results of a study to develop a data base for logging residue in Montana that would: (1) provide the means to make site-specific assessments of logging residue for either wood products or energy, and (2) provide parity in residue information with other northwest States, thereby aiding regional energy planning and assessment.

The study had two primary objectives. The first was to develop appropriate analytical tools for estimating the volume of logging residue for any uniquely defined supply zone in Montana. Volume estimators (ratios) developed in this study relate residue volume to both volume and acreage of timber harvest. One ratio gives the cubic-foot volume of residues associated with the harvest of 1,000 board feet of timber (CF/MBF). The other ratio gives cubic-foot volume of residue per acre harvested (CF/AC). An example is provided to demonstrate practical application of these ratios.

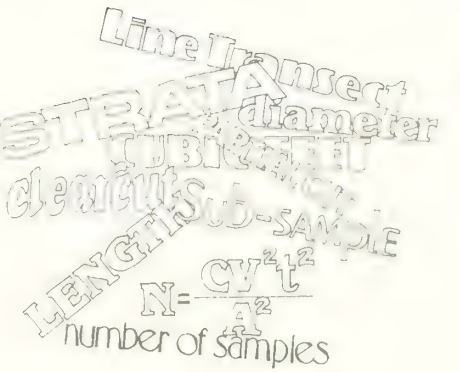
The second objective was to describe and classify logging residue by the following characteristics that affect utilization:

(1) Gross and net volume, by diameter and length classes, for live, and dead or cull material.
(2) Number of pieces per acre, by diameter and length classes.
(3) Volume by percent sound (chippable), in cubic feet per acre.
(4) Accessibility on cutover areas, by slope and distance to road.
(5) Volume, by product potential class.

Ratios and characteristics for residue are displayed for four strata. Three are based on owner class- harvest method (public—clearcut; public—partial cut; private—all harvest methods), one on forest type (lodgepole pine). These strata were selected on the basis of differences in residue volume associated with harvesting methods, and existing information on residue characteristics (Benson and Schlieter 1980).

Results are based on measurements of logging residue on 120 cutover units, made during the summer of 1982.

Study Design



Designing the study included the following steps: (1) determining sample size and allocation and selecting cutover areas to be sampled, (2) establishing procedures for sampling residue volume and characteristics, and (3) selecting procedures for computing ratios and characteristics of residue. Each of these steps is discussed.

Sample Size and Allocation

Sample stratification was based on timber ownership, harvest method, and forest type. Harvest data had indicated that there were three significant classes of owner and harvest methods in Montana. Only two classes of ownership, public and private, were identified. Most of the timber harvest on public land is on National Forests, and most of the harvest on private land is on industry-owned land. There was not enough harvest in any other ownership class to warrant a separate stratum. In terms of harvest method, only in the public sector is enough timber harvested by clearcutting to justify a separate stratum. Estimates of residue volume and characteristics for the private stratum represent the mix of harvest methods that were being used at the time of the study. This mix is not expected to change much from year to year.

A separate stratum based on forest type was used for lodgepole pine. Studies by Benson and Johnson (1976, 1980) indicate that residue in the lodgepole pine type is significantly different in character from that of other forest types. Lodgepole pine is also the most common species in Montana, occupying nearly one-third of the commercial forest land (Barger and Fiedler 1981). Furthermore, because lodgepole typically occurs in large, nearly pure stands, annual harvest and acreage can be identified in the data bases of major land owners.

The four strata identified for the study are:

Public, clearcut
Public, partial cut
Private, all harvest methods
Lodgepole pine, all harvest methods and land owners.

Following identification of study strata, the next step was to determine sample size for each stratum.

Sample size was determined by computation or rule-of-thumb, depending on available information.

Where information was available from which expected variation could be estimated, sample size was determined by the following formula:

$$N = \frac{CV^2 t^2}{A^2}$$

where: N = stratum sample size,
CV = coefficient of variation
t = Student's t-value
A = desired level of precision.

The values for t and A were fixed so that the computed sample size would result in an estimated average residue volume per stratum within ±20 percent of the true average 9 times out of 10 (90 percent level). Coefficient of variation for logging residue volume (per acre) was used to compute sample size. This was done because the major contributor to total variance was assumed to be that associated with average residue volume (per acre). Values for CV were derived from previous studies where similar population characteristics were observed (Howard 1978, 1981a).

For the lodgepole pine stratum there was no comparable data from which estimates of variation could be derived. For this stratum sample size was set at 25. This number was considered adequate to provide results comparable to those from the other strata. Sample size determined for each stratum is shown below.

Stratum	Number of Samples
Public, clearcut	25
Public, partial cut	35
Private, all harvest methods	35
Lodgepole pine	25
Total	120

Sample Selection

Specific cutover areas were selected following determination of sample size for each stratum. The basic approach was to identify all cutover areas (the sample population) by stratum. The desired number of samples was then selected from this population.

The overall sampling scheme is a two-stage sample, with PPS (probability proportional size) sampling being the first stage. The second stage, residue sampling on each cutover unit, will be discussed later. In the first stage, PPS sampling was conducted for each of the four strata. Following PPS sampling procedures, all qualifying cutover units were listed, along with acres harvested. These acreages were accumulated, and random numbers used to select specific units for sampling. Under this procedure larger cutover areas have a greater chance of being selected, because each acre, in effect, has equal weight. Because sampling was done with replacement, some cutover units were selected more than once. For these units, residue measurements were made once, then replicated for each additional time the unit was selected.

Determining the sample population generally followed one of two procedures. For some ownerships it was possible to obtain a list of all areas cut over during the study period, January 1, 1981, to September 1, 1982. For other ownerships it was more efficient to use lists of *only* those cutover areas that met study criteria. Sample units were selected from those lists.

All cutover areas selected, regardless of which procedure was used, had to meet five criteria to be considered for study. Criteria were:

1. Logging was completed after January 1, 1981, and prior to September 1, 1982.
2. The unit was 5 acres or larger.
3. The unit had not been burned following logging.
4. The unit was not a fire salvage sale.
5. Logging residue on the unit had not been utilized by cull log salvagers, firewood cutters, or secondary operators.

These criteria were established to insure that residue estimates would be representative of normal harvesting situations.

A larger number of sample units was selected than dictated by the sampling process described. The extra units served as alternates to replace areas that failed to meet study criteria upon field examination. Alternate sample units for each stratum were used in the order in which they were drawn.

Following identification of the cutover areas to be sampled, each owner was contacted and asked to provide maps, location data, and information concerning characteristics of the area.

Specific information collected for each sample was:

1. Age of the timber harvested.
2. Acreage of the area harvested.
3. Type of logging equipment used.
4. Percentage contribution of the three major species harvested (set to 100 percent).
5. Volume of timber harvested, in thousand board feet per acre.

Residue Sampling Techniques

The average volume of residue on each cutover area was derived by three procedures. The line intersect method was used to obtain an estimate for scattered materials and small piles (Howard and Ward 1972). A pile

volume estimator, obtained from a separate study, was used to determine the volume in large piles (Little 1982). The volume of bark was derived by using bark-to-wood factors, obtained from a companion study (Snell and Max 1982). Information on characteristics of the residue was derived from a subsample of pieces measured for volume estimation.

Estimating scattered residue.—The line intersect method was used to estimate the volume of all residue material 3.01 inches in diameter (d.i.b.) and larger and 1.0 foot in length and longer, not found in large piles. The line intersect method has been widely used for estimating residue, and has been demonstrated to be efficient and unbiased (Pickford and Hazard 1978).

The sample design used in this study consisted of 200-foot line transects located at each of 30 points on a systematic grid (fig. 1).

The interval between grid points varied with size of the cutover area. Except on very large partial cuts, the fluctuating grid interval resulted in a pattern that covered the entire cutover area. The maximum grid interval was set to cover about 200 acres. For larger areas, yarding practices are such that residue piles are created throughout the area, rather than at a central location. Both scattered residue and piles, therefore, tend to be associated with the surrounding harvesting pattern. Thus, the sample design results in estimates of residue that are representative of the harvest practice within the grid pattern.

To reduce bias, both the initial starting point and the base line for the grid system were randomly selected. To reduce piece orientation bias (Howard and Ward 1972), each of the 30 line transects was randomly oriented along 45-degree azimuths.

Measurements were taken for all qualifying residue intersected by the 200-foot line transects. Only pieces at least 3.01 inches in diameter (d.i.b.) and 1.0 foot in length were considered measurable. Older dead pieces that were rotten to the point of losing their original form were excluded (fig. 2).

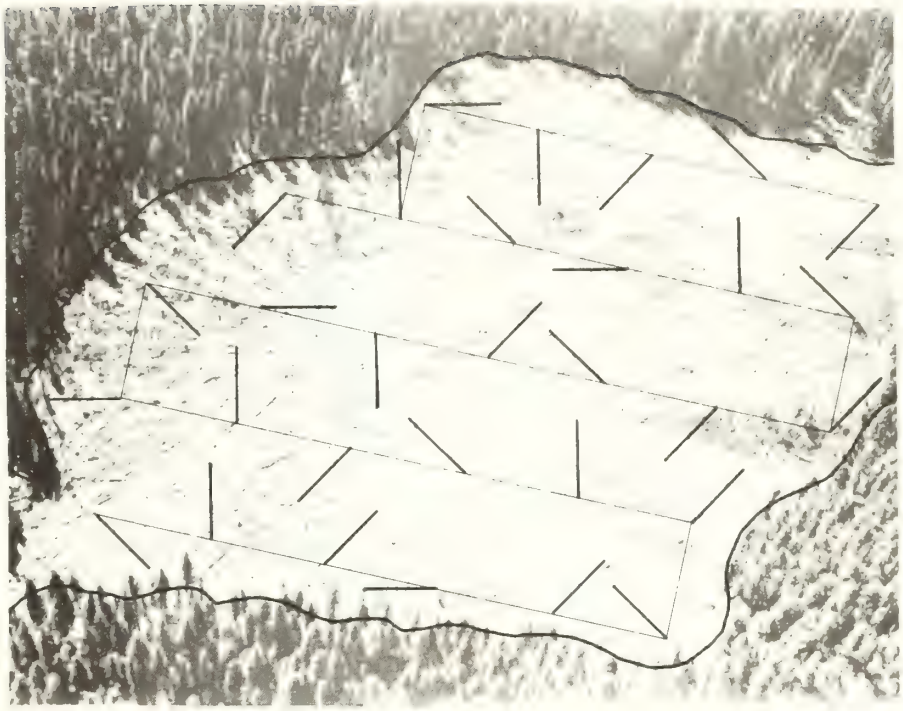


Figure 1.—Example of sampling grid for a cutover area.

Figure 2.—Deteriorated logs were not included in the study.

Measurements recorded for each piece of residue were:

1. Diameter inside bark (d.i.b.) at the point of intersection with a transect line.
2. Net chippable content at the point of intersection with a transect line.
3. Origin of the piece (live, or dead or cull at the time of harvesting).

These are the only measurements required to provide an estimate of gross and net volumes of scattered logging residue and small piles for a specific cutover area.

Estimating pile volume.—The line intersect method cannot be used to estimate residue in large piles (fig. 3), because many pieces in the interior of such piles are impossible to observe without taking the pile apart. Since destructive sampling of piles was not within the scope of this study, a separate procedure was used to estimate pile volume.

The procedure for estimating the volume of residue in large piles involved two steps. First, each pile was visually classified as one of four geometric solids shown in figure 4. Then the dimensions appropriate for the selected shape were recorded to the nearest foot.

The geometric volume of each pile was then computed from these measurements and converted to solid wood content according to procedures described by Little (1982).

Net (chippable) volume and origin of residue in large piles had to be derived by other means.

Net volume was derived by using data from an earlier study (Howard 1978) of residue from the harvest of old-growth timber with characteristics generally similar to those found in this study. The proportion of net volume to gross volume (0.54) from the 1978 study was applied to the gross residue volume of each pile to obtain net volume.

The proportion by live and dead or cull material in each pile was estimated by field personnel.

Figure 3.—Large piles of residue required separate procedures for estimating volume.

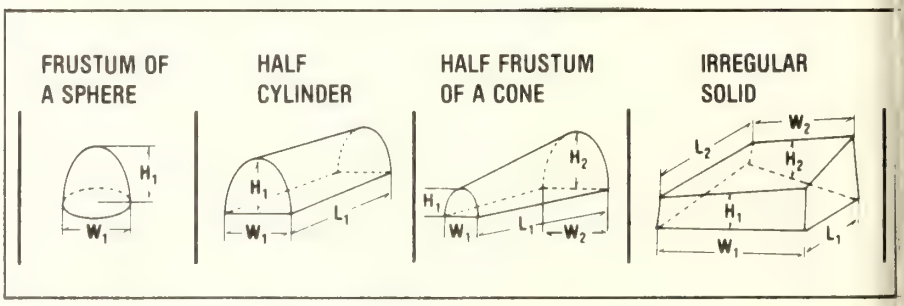


Figure 4.—Geometric solids and related dimensions used for estimating the volume of residue in piles.

Estimating bark volume.—Diameters of residue pieces were measured inside the bark (d.i.b.) to avoid problems associated with voids when outside-bark measurements are taken (fig. 5). Bark, however, is an important raw material, particularly for energy conversion. Thus another method was required to estimate bark volume. Ratios of bark-to-wood were developed for the major species, based on data from a study of bark samples from 50 cutover areas in Idaho, Oregon, and Washington (Snell and Max 1982).

A weighted average bark factor was computed for each sample unit using harvest volume by species. These ratios were then applied to wood residue volume to generate estimates of wood and bark volume.

Estimating residue characteristics.—To provide data on size and number of pieces and their product potential, additional measurements were made on a subsample of all residue pieces measured to estimate volume. The subsample consisted of all residue pieces encountered on the first 40 feet

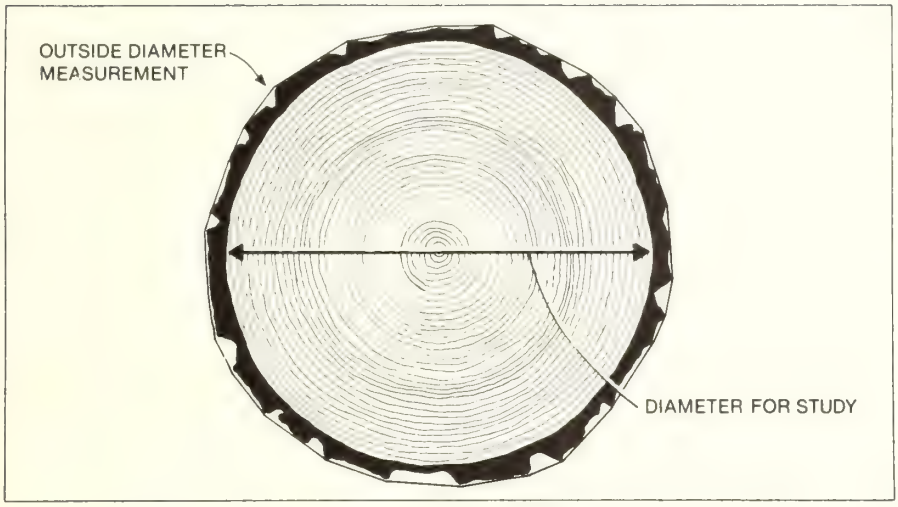


Figure 5.—Voids associated with irregularities in bark were avoided by making inside-bark measurements.

of each 200-foot line transect. This resulted in a subsample of 20 percent of the total number of pieces measured for volume.

The measurements for pieces in the subsample were:

1. Small end diameter (d.i.b.), to the nearest inch.
2. Diameter (d.i.b.) at intersection with line transect.
3. Length, to the nearest foot.
4. Net chippable content.
5. Live, or dead or cull at time of logging.
6. Product potential.

Items 2 and 4 were recorded both for the subsample and for the line-transect volume estimate.

Three classes of product potential were recognized, and recorded for all residue not in large piles. These classes were defined as follows:

Class	Product potential	Definition
0	Fiber only	Not meeting the standards for classes 1 and 2
1	Post or pole	minimum diameter, 3 to 6 inches minimum length, 8 feet maximum sweep. 1 inch 100-percent sound
2	House or saw log	minimum diameter greater than 6 inches minimum length, 8 feet maximum sweep, 1 inch 100-percent sound

Following completion of the transect measurements, all residue, including piles, was visually classified by the following slope and distance-to-road categories:

Slope: 0-35 percent
over 35 percent

Distance to road: 0-500 feet
501-1,000 feet
over 1,000 feet

Roads are defined here as any roadbed capable of handling log trucks and other logging-related equipment. In tractor-logged areas, especially those with flat terrain, acceptable roads are frequently of lower quality than those associated with steeper slopes.

Computational Procedures

The volume of residue recorded by the line-intersect method was computed by the following formula:

$$V = \frac{\pi^2 D^2}{8L} \cdot \frac{43{,}560}{144};$$

where: V = volume of each piece of residue, in cubic feet per acre (CF/AC);
D = diameter inside bark, in inches, of each piece of residue; and
L = total length of transect lines (6,000 feet).

The sum of the computed transect volume for each piece yields average gross volume (CF/AC) of residue for a specific cutover area. As discussed above, the volume of piles, where present, was computed separately. The total volume of residue in piles for each sample area was divided by the acreage of the area, to estimate the average of wood in piles on a per-acre basis. This figure was then added to the transect volume to obtain the overall gross wood residue volume for each cutover ara. Estimates of residue including bark were derived by applying the bark-to-wood ratios described above. Net chippable volume was computed from information collected for each piece tallied along the transects, and from the pile estimation process described earlier.

hese computations provided esti-
ıates of residue in cubic feet per acre.
major objective of this study, how-
ver, was to provide ratios of cubic
eet of residue to 1,000 board feet of
mber harvested (CF/MBF). To obtain
is ratio for a particular cutover area,
ıe average volume of residue (CF/AC)
as divided by the average harvest
olume (MBF/AC). This is shown by:

$$\text{atio}_i = \frac{(\text{Residue volume})_i}{(\text{Harvest volume})_i}$$

$$= \frac{(\text{CF/AC})_i}{(\text{MBF/AC})_i}$$

$$= (\text{CF/MBF})_i ;$$

here: $i = i^{th}$ cutover area (sample unit).

stimating average residue volume for
specific stratum required a further
omputational step. The use of PPS
ampling, described earlier, results in
ıe CF/AC-volume of each unit having
qual weight. The estimate for each
ratum, therefore, is the arithmetic
verage of all units in the stratum. This
represented by:

$$\text{F/AC}_j = \frac{\sum_{i=1}^{n} a_{ij}}{n} ;$$

here: a_{ij} = per-acre residue volume for i^{th} sample in j^{th} stratum; and
n = number of sample units in j^{th} stratum.

he CF/MBF ratio for a stratum is
imilarly computed, using a ratio of
ıe means approach. The formula for
omputing the ratio for a specific
tratum is represented by:

$$\text{atio}_j = \frac{\dfrac{\sum_{i=1}^{n} a_{ij}}{n}}{\dfrac{\sum_{i=1}^{n} h_{ij}}{n}} ;$$

where: a_{ij} and n are as defined above for CF/AC_j; and
h_{ij} = per-acre harvest volume for i^{th} sample unit in j^{th} stratum.

Computing the volume for characteristics of residue is based on subsample measurements. The volume of each subsample piece is the same as that used for estimating the volume of the unit (CF/AC).

The gross volume of all pieces was summarized by diameter and length classes for each cutover area. A proportion was developed to relate the accumulated subsample volume to the total volume estimated from the line transects. This proportion was then used to adjust the subsample volume in each diameter/length class to reflect the computed residue volume for each cutover area. To obtain number of pieces per acre by diameter/length class, the adjusted volume for each class was then divided by the average piece volume for the class. Product potential was computed in a similar manner. The product potential of each subsample piece was coded in the field. The subsample volume for each product-potential class was accumulated and adjusted to the transect volume estimate by the method described above.

Net chippable volume for residue characterization was computed using item 4 of the subsample measurements.

Stratum averages of residue characteristics were computed in a manner similar to that described above. In effect, residue characteristics were developed, using all subsample pieces in each stratum and the average volume estimate for that stratum.

Residue Volume Estimators

Ratios for estimating logging residue volume are presented in two forms. One ratio relates the cubic-foot volume of residue to 1,000 board feet of timber harvested (CF/MBF). The other gives residue volume in terms of cubic feet per acre (CF/AC). Both ratios have value, depending upon the user's need and the availability of supporting data. Estimates of residue volume are obtained by applying the appropriate ratio to timber harvest volume or acreage for each stratum within the geographic area to be assessed.

A wide range of potential uses can be made of the tables, which show gross and net volumes of residue, with and without bark, and live versus dead or cull material. The appendix includes conversion tables for metric values and wood density and energy values for selected species. Also in the appendix are selected tables from a similar study conducted in Idaho, Oregon, and Washington. These tables are included to aid in comparing residue volume across the four-State area.

It is especially important to understand that estimates based on data from this report indicate only the existence of residue material. The availability of materials for conversion to energy, pulp, or other products depends on a wide range of factors, such as competing uses, intent of the landowners, environmental concerns,and cost. Many other factors influence the accumulation of residue but are beyond the scope of this report. Ultimately, it is the responsibility of analysts to determine the volume of residue that can be considered available.

Ratios of residue volume to harvest volume.—Table 1 gives the ratios of residue volume to harvest volume for gross and net volume of logging residue, with and without bark, for each of the study strata. Net volume represents the chippable portion of the residue, or that considered usable for fiber-oriented products. A variety of defects, such as cracks, checks, or early stages of rot, make much of this material unusable for solid wood products. Whatever product is considered, it should be recognized that some unusable material would have to be removed to recover the desired portions.

Gross volume represents the bulk or mass of logging residue, based on external dimensions. This measurement includes space not occupied by wood fiber, such as hollow logs (fig. 6) and pieces with splinters or chunks missing. Gross volume also includes material too rotten to have product value. The extreme example is a piece that has gross volume but no chippable material.

Gross volume is important to measure because it represents material that has to be removed or otherwise treated to reduce its impact on the site. Residue has impacts on reforestation, esthetics, environmental quality, wildlife habitat, stand management activities, and fire hazard. Given these relationships, a measure of gross residue volume is important in the broad context of residue management.

Estimates of gross volume of residue are also important for determining equipment requirements, and the cost of handling and transporting residue. While the net volume of residue represents product quantity and value, it is the gross volume that must be handled to recover the usable portions.

The volume of residue for a specific area can be estimated, using timber harvest data for the area and ratios available in table 1. A separate ratio and timber harvest figure should be used for each stratum represented in the geographic area being examined. These ratios, and other data in this report, are representative of current harvesting practices and markets and should remain useful as long as harvesting technology, stand conditions, and the current product mix do not change significantly.

Table 1—Average gross and net volume of logging residue per thousand board feet of timber harvest by wood only, by wood and bark, and by stratum

Stratum	Wood		Wood and bark	
	Gross	Net	Gross	Net
	Cubic feet per thousand board feet of timber harvest			
Public:				
Clearcut	121	75	142	95
Partial cut	148	78	173	103
Private 1/	185	102	221	137
Lodgepole pine 2/	146	91	162	107

1/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

2/ Samples were selected from all harvest methods and ownership classes.

Figure 6.—Hollow logs have gross volume, represented by external dimensions, that includes space without usable wood fiber.

The ratios of residue volume to harvest volume in table 1 are similar to those reported for Idaho in an earlier study (Howard 1981a). A comparison of the two studies shows the Montana ratios to be somewhat lower for public lands than in Idaho, but 15 to 25 percent higher for private lands. The CF/MBF ratios in Montana are generally higher than in the coastal areas of the Pacific Northwest. The opposite is true for per-acre residue volume, however, because harvest levels are greater in the coastal areas.

Also affecting the residue situation in Montana is the relatively high level of mortality in lodgepole pine stands. Log markets have not been able to cope with the large volume of recently killed lodgepole pine. Thus, where it is mixed with other species, the lodgepole may be cut but not as fully utilized, partly because of the relatively high number of small stems. The result is higher levels of residue than would otherwise be the case.

The following tabulation compares the net volume of residue to gross volume for each stratum:

Stratum	Net volume as a percent of gross volume
Public: Clearcut	62
Public: Partial Cut	53
Private	55
Lodgepole pine	62

The percentage of net volume is somewhat higher for clearcuts and lodgepole pine than for the other two strata, which are predominately partial-cut harvesting. The reason is that most partial cutting is oriented to a specific product or to a tree-class. Thus, material not sought is frequently not removed (previously down and dead material, for example). In clearcutting, however, nearly all trees are cut, exposing all timber to the possibility of removal, based on marginal product value of each piece. Material that was down and dead prior to harvest usually has more defect than green timber. Therefore, a higher average percent defect of residue would be expected for partial-cut areas.

Much of the lodgepole pine recently killed by insects had not incurred extensive decay at the time of this study. Lodgepole also does not have as much heart rot as other species have. These two factors result in a higher percentage of chippable residue.

Ratios of residue volume to area harvested.—Ratios of cubic feet of residue to acres harvested are valuable expressions of the quantity of logging residue. Per-acre volume is especially useful for making economic assessments and evaluating residue management alternatives. Table 2 gives the average gross and net residue volume per acre, by stratum, for wood only and for wood and bark. These data can be used to estimate residue volume when the number of acres harvested is known for a given stratum.

The information in table 2 can be used to compare relative densities of residue between strata to aid in setting priorities for utilization or treatment options. Greater concentrations of residue, for example, are generally more feasible to recover than small quantities. Thus, use of the above data would help identify broad acreage groupings having the greatest potential.

Historically residue volume has been expressed in cubic feet per acre. Thus where similar data are available, it is possible to determine trends in timber utilization, or conversely, residue levels.

Table 2—Average gross and net per-acre volume of logging residue by wood only, by wood and bark, and by stratum

Stratum	Wood		Wood and bark	
	Gross	Net	Gross	Net
	Cubic feet per acre			
Public:				
Clearcut	2,021	1,246	2,369	1,594
Partial cut	1,578	831	1,846	1,100
Private 1/	1,345	737	1,602	994
Lodgepole pine 2/	1,816	1,128	2,009	1,321

1/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

2/ Samples were selected from all harvest methods and ownership classes.

Special relationships.—Tables 3 and 4 provide additional insight into residue. These data show the percent of residue that was dead or cull at the time of harvest and the percent of volume in large piles.

As noted earlier, the percent of residue volume made up of previously dead or cull material is higher on partial-cut areas than on clearcuts. This is borne out by information in table 3. Roughly 55 to 70 percent of gross residue volume was from trees that were dead or cull at the time of harvest. For net volume the percentage was somewhat lower. This is explained by the fact that both dead and cull material have more defect than green timber, and thus account for a lower proportion of the chippable volume of residue.

These data are especially useful in projecting timber inventories. Because material that was dead or cull before harvest has been accounted for by mortality and defect figures in current inventory data, only the portion of logging residue from live trees needs to be deducted to complete the estimate of inventory drain.

The data in table 4 show the relative contribution of the volume in large residue piles to overall stratum averages.

In Montana the percent of residue volume in large piles is higher than in all but one stratum in the three-State report(Howard 1981a). The Montana figures are comparable only with National Forest clearcuts in Idaho. Explanation of these differences is beyond the scope of this report. The differences emphasize the need to ascertain timber sales policies when studying the feasibility of utilizing residue.

Table 3—Material dead and cull (wood only) at time of harvest as a percentage of average gross and net residue volume, by stratum

Stratum	Gross volume	Net volume
	Percent dead and cull	
Public:		
Clearcut	54	40
Partial cut	69	53
Private 1/	63	48
Lodgepole pine 2/	65	55

1/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

2/ Samples were selected from all harvest methods and ownership classes.

Table 4—Volume of residue in large piles as a percent of gross and net volume (wood only), by stratum

Stratum	Gross volume		Net volume	
	Average	Highest	Average	Highest
	Percent			
Public:				
Clearcut	22	89	19	87
Partial cut	12	89	12	90
Private 1/	25	85	24	79
Lodgepole pine 2/	29	82	25	80

1/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

2/ Samples were selected from all harvest methods and ownership classes.

Tables 5 through 9 concern only residue that is scattered throughout the areas sampled and do not include residue in large piles. Table 10 pertains to distribution of all residue, including that in large piles. Six additional tables (13 through 18 in the appendix) provide a breakdown indicating whether the material was live or dead or cull at the time of harvest.

Volume by Diameter and Length Classes.—Tables 5 and 6 give the distribution of gross and net residue volume (wood only) for each of the study strata. The gross volume table represents material that must be handled, whether for product recovery or treatment. Net volume represents the chippable content of residue. Thus even if product recovery is the major objective, gross volume is an important consideration.

The data are reported here in cubic feet per acre because feasibility studies usually involve per-acre figures. In some situations it may be desirable to relate residue characteristics to cubic feet per 1,000 board feet of harvest volume. This can be accomplished by determining the desired relationship of gross or net volume from these tables and applying it to CF/MBF volume estimates on a percentage basis.

Table 5—Gross volume (wood only) of logging residue, by diameter and length classes and by stratum[1]

Stratum	Small end diameter	Length (feet) 1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Cubic feet per acre						
Public:								
Clearcut	3.0- 3.9	12	24	29	105	143	81	389
	4.0- 4.9	20	21	17	43	51	23	175
	5.0- 5.9	8	17	13	38	25	14	115
	6.0- 6.9	23	15	12	39	40	26	155
	7.0- 7.9	3	7	13	21	17	11	72
	8.0-11.9	19	36	33	77	69	46	280
	12.0-15.9	12	17	19	40	41	33	162
	16.0-19.9	4	0	17	43	37	19	120
	20.0+	8	13	0	18	51	15	105
Total		109	150	153	424	469	268	1573
Partial cut	3.1- 3.9	8	15	14	66	88	81	272
	4.0- 4.9	10	14	8	38	40	48	158
	5.0- 5.9	3	10	10	23	24	20	90
	6.0- 6.9	8	9	9	33	38	52	149
	7.0- 7.9	7	7	5	22	29	12	82
	8.0-11.9	11	20	20	61	93	62	267
	12.0-15.9	13	14	9	48	35	40	159
	16.0-19.9	8	0	2	24	29	47	110
	20.0+	0	12	7	31	32	20	102
Total		68	101	84	346	408	382	1389
Private 2/	3.1- 3.9	11	13	16	51	79	40	210
	4.0- 4.9	9	12	9	32	28	14	104
	5.0- 5.9	4	7	6	20	16	6	59
	6.0- 6.9	6	11	9	27	19	8	80
	7.0- 7.9	0	6	6	23	10	5	50
	8.0-11.9	12	23	20	50	42	29	176
	12.0-15.9	9	14	12	36	36	21	128
	16.0-19.9	5	4	10	13	32	8	72
	20.0+	15	26	14	14	32	32	133
Total		71	116	102	266	294	163	1012
Lodgepole pine 3/	3.1- 3.9	17	22	23	92	150	92	396
	4.0- 4.9	24	30	19	53	62	28	216
	5.0- 5.9	8	16	13	34	32	16	119
	6.0- 6.9	14	18	15	23	41	35	146
	7.0- 7.9	3	5	10	24	24	6	72
	8.0-11.9	13	32	17	56	68	27	213
	12.0-15.9	10	6	8	15	12	8	59
	16.0-19.9	0	4	3	21	16	3	47
	20.0+	0	0	0	15	0	15	30
Total		89	133	108	333	405	230	1298

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

The data in tables 5 and 6 can be used to determine the relationship between gross and net residue volume for any size class, or above or below a certain utilization standard. For example, the following tabulation compares gross and net volume for two size categories on public clearcuts in Montana:

Diameter/length class	Residue volume: Gross	Residue volume: Net
	(CF/AC)	
Diameter: 3.1-3.9 inches Length: 8.0-15.9 feet	105	102
Diameter: 16.0-19.9 inches Length: 8.0-15.9 feet	43	17

Table 6—Net volume (wood only) of logging residue, by diameter and length classes and by stratum[1]

Stratum	Small end diameter	Length (feet) 1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Cubic feet per acre						
Public:								
Clearcut	3.1- 3.9	9	21	27	102	138	76	373
	4.0- 4.9	13	16	14	37	48	19	147
	5.0- 5.9	4	11	11	29	18	10	83
	6.0- 6.9	11	8	7	28	25	19	98
	7.0- 7.9	2	3	9	13	12	7	46
	8.0-11.9	5	10	18	44	33	25	135
	12.0-15.9	6	3	8	20	18	12	67
	16.0-19.9	1	0	2	17	14	5	39
	20.0+	3	5	0	0	6	1	15
Total		54	77	96	290	312	174	1003
Partial cut	3.1- 3.9	5	11	9	53	68	61	207
	4.0- 4.9	5	9	5	28	28	31	106
	5.0- 5.9	2	5	7	15	12	9	50
	6.0- 6.9	4	4	5	15	20	29	77
	7.0- 7.9	1	3	3	8	10	8	33
	8.0-11.9	4	8	8	27	36	32	115
	12.0-15.9	10	6	4	21	13	10	64
	16.0-19.9	5	0	0	9	8	17	40
	20.0+	0	9	6	10	4	8	37
Total		37	55	47	186	199	205	729
Private 2/	3.1- 3.9	8	10	12	45	71	37	183
	4.0- 4.9	5	7	6	25	22	9	74
	5.0- 5.9	1	4	5	14	11	3	38
	6.0- 6.9	1	6	5	15	10	4	41
	7.0- 7.9	0	3	2	11	5	3	24
	8.0-11.9	6	11	11	21	20	13	82
	12.0-15.9	8	6	6	10	9	5	44
	16.0-19.9	2	1	5	2	9	1	20
	20.0+	5	16	5	3	19	3	51
Total		36	64	57	146	176	78	557
Lodgepole pine 3/	3.0- 3.9	12	19	17	79	133	77	337
	4.0- 4.9	15	20	14	41	46	20	156
	5.0- 5.9	4	10	8	22	21	9	74
	6.0- 6.9	7	9	11	12	22	17	78
	7.0- 7.9	1	4	5	15	16	3	44
	8.0-11.9	7	16	11	31	28	9	102
	12.0-15.9	9	3	2	8	3	1	26
	16.0-19.9	0	3	3	5	10	1	22
	20.0+	0	0	0	9	0	0	9
Total		55	84	71	222	279	137	848

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

In this example nearly all the gross volume (about 93 percent) in the smaller diameter class (3.1 to 3.9 inches) is sound. But in the larger diameter class only 17 cubic feet, or 40 percent, of the gross volume is chippable. This type of information is critical in evaluating the net fiber cost when assessing utilization of residue materials.

The relatively small diameter of lodgepole pine timber is a factor in its utilization as timber and as residue. Table 5 shows that only 27 percent of the residue in the lodgepole pine stratum is 8 inches or greater in diameter, small end. For the other three strata, residue 8 inches or greater makes up 41 to 49 percent of total gross volume.

Tables 13 through 16 in the appendix provide additional data on the portion of residue that was live, or dead or cull at the time of harvest. This information may be especially significant if product options differ for green versus dead or cull material.

Percent chippable.—The suitability of logging residue for a given product usually depends on physical characteristics of the material. A key factor is the nature and amount of defect acceptable for a given type of product. Checking and splitting, for example, make wood less suitable for sawn products but have no effect on the quantity or quality of wood chips. Likewise, decay beyond the very early stages may prohibit use for pulp but not necessarily for energy

Assessment of the cost and returns of converting residue into a particular product requires that the acceptable level of defect be defined. Material that does not meet this standard is rejected as having too little usable content to justify the cost of handling and processing. The data presented in table 7 can be used in making this evaluation. Gross and net volume of scattered residue are given for seven classes of chippability. These data can be applied to figures in tables 5 and 6 to further refine estimates of residue volume that can be considered economically available.

Following is an example of how to interpret the data in table 7. In the private stratum gross volume of residue in the 61- to 80-percent-chippable class is 86 cubic feet per acre. Net volume for this class is 60 cubic feet per acre. Thus, 86 cubic feet would have to be processed to recover 60 cubic feet of usable wood fiber. This net volume is not synonymous with recovery of solid wood products because defects such as cracks, splits and early stages of decay greatly reduce usability for these products Therefore, the data in table 7 cannot be used to make precise assessments of solid product potential

Table 7—Gross and net volume (wood) of logging residue, by percent of chippable material and by stratum[1]

Stratum	Volume	Percent chippable							
		0	1-20	21-40	41-60	61-80	81-99	100	Total
		Cubic feet per acre							
Public:									
Clearcut	Gross	142	236	129	115	127	285	539	1573
	Net	0	24	39	57	88	256	539	1003
Partial cut	Gross	172	295	151	117	119	219	316	1389
	Net	0	29	45	58	83	198	316	729
Private 2/	Gross	120	208	95	85	86	126	292	1012
	Net	0	21	29	42	60	113	292	557
Lodgepole pine 3/	Gross	94	197	90	102	108	314	393	1298
	Net	0	20	27	51	76	281	393	848

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Number of pieces per acre.—The cost of retrieving residue material is a critical factor in decisions about utilization. Because equipment needs and costs of handling residue vary considerably, it is necessary to know number of pieces and volume by size classes. This information is provided by table 8. Tables 17 and 18 in the appendix show number of pieces per acre by live versus dead or cull.

Because the data in table 8 are averages for each stratum, the tabulations include fractions of pieces. In actuality, certain diameter or length classes may be represented on some cutover areas but not on others. This is particularly true for the larger size classes. What is important, however, is whether there are few or many pieces of a given size

Volume per piece may be important in some assessments of logging residue. Tables 5 and 8 can be used to estimate the average gross volume per piece by dividing the volume of residue in a specific diameter and length class by the number of pieces in that class. For example, table 5 shows that in the private stratum pieces 3.1 to 3.9 inches in diameter and 6.0 to 7.9 feet long have a gross volume of 16 cubic feet per acre. Table 8 shows that for the same size class there are 17.0 pieces per acre. Therefore, the average volume per piece is about 0.94 cubic feet. Table 6 can be used to find the net volume per piece in a similar fashion.

An interesting comparison between volume per acre and number of pieces per acre can be made by using data from tables 5 and 8. The tabulation below compares the gross volume (table 5) of residue less than 6 inches in diameter with the number of pieces (table 8) less than 6 inches in diameter. Residue less than 6 inches made up the following percentages of stratum totals:

Stratum	Percent of gross volume	Percent of total pieces per acre
Public:		
Clearcut	44	79
Partial cut	37	74
Private	37	77
Lodgepole pine	56	83

These results show that although the number of pieces of residue less than 6 inches is quite high, the volume in these pieces constitutes less than half the total gross volume. The lone exception is the lodgepole pine stratum, where both figures are higher than for the other strata.

Product potentials.—In Montana there is an active market for house logs, posts, and poles. Because of this, options for utilizing logging residue frequently include recovery of these higher value products. With this situation in mind, residue in the subsample was recorded in one of three categories of product potential, as defined earlier in this report (table 9). It is important to bear in mind, however, that the minimum standards had to be met for only a portion of each piece; a piece of residue could meet the standard for house logs for part of its length, yet be classed as a post, pole, or fiber log for the remaining portion. In all cases the product of highest value was recorded for each piece.

The breakdown of live versus dead or cull shown in table 9 was provided for situations where quality considerations might dictate use of live material only. As in the previous tables in this section, large piles are excluded.

Residue distribution.—The distribution of residue over harvested areas is important in decisions concerning equipment needed to utilize these materials. Two factors that affect the type of equipment used to retrieve residue are slope and distance to the nearest road. The degree of slope on the harvested area determines whether ground-based or cable systems are required to yard the residue. Equipment limitations, such as maximum yarding distance, are determined by distance from the landing at roadside. As a rule, relogging does not recover the cost of new road construction, thus roads built during initial logging will generally be used for residue recovery operations.

Table 10 gives the average distribution of logging residue on cutover areas by slope and distance to the nearest road. This table includes residue in large piles, which are usually located adjacent to roads.

Table 8—Average number of pieces of logging residue per acre, by diameter and length classes and by stratum[1]

Stratum	Small end diameter	Length classes (feet) 1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Number of pieces per acre						
Public:								
Clearcut	3.1- 3.9	18.0	34.4	33.2	99.3	113.1	46.2	344.2
	4.0- 4.9	19.7	17.3	13.3	30.0	30.3	9.1	119.7
	5.0- 5.9	4.5	8.6	6.3	17.4	8.8	4.1	49.7
	6.0- 6.9	10.0	6.7	4.4	14.0	12.5	5.6	53.2
	7.0- 7.9	1.2	1.6	3.5	5.5	3.8	1.7	17.3
	8.0-11.9	3.5	6.2	5.2	11.6	9.7	4.7	40.9
	12.0-15.9	1.1	1.6	1.5	3.3	3.1	2.0	12.6
	16.0-19.9	.3	0	.9	2.2	1.5	.9	5.8
	20.0+	.2	.4	0	.5	1.4	.5	3.0
Total		58.5	76.8	68.3	183.8	184.2	74.8	646.4
Partial cut	3.1- 3.9	11.8	20.6	15.5	64.8	70.1	38.8	221.6
	4.0- 4.9	9.7	11.6	6.3	26.0	21.4	16.8	91.8
	5.0- 5.9	1.7	5.5	5.1	9.8	8.7	6.3	37.1
	6.0- 6.9	3.2	3.4	3.7	11.6	10.3	9.4	41.6
	7.0- 7.9	2.0	2.1	1.4	5.6	7.0	2.4	20.5
	8.0-11.9	2.4	3.7	3.4	9.6	13.2	6.9	39.2
	12.0-15.9	1.3	1.2	.6	3.7	3.1	2.3	12.2
	16.0-19.9	.4	0	.2	1.3	1.4	1.7	5.0
	20.0+	0	.3	.2	1.0	.7	.4	2.6
Total		32.5	48.4	36.4	133.4	135.9	85.0	471.6
Private 2/	3.1- 3.9	17.0	17.9	17.0	49.4	59.5	20.7	181.5
	4.0- 4.9	9.3	9.5	7.7	20.1	14.3	4.4	65.3
	5.0- 5.9	2.4	3.4	2.8	9.4	5.6	1.9	25.6
	6.0- 6.9	2.4	4.4	3.0	9.4	5.5	1.5	26.2
	7.0- 7.9	.2	1.6	1.4	5.3	2.3	1.2	12.0
	8.0-11.9	2.2	3.6	3.1	8.1	6.0	3.5	26.5
	12.0-15.9	.8	1.3	1.0	2.9	2.7	1.3	10.0
	16.0-19.9	.3	.2	.4	.7	1.3	.4	3.3
	20.0+	.4	.6	.3	.4	.8	.6	3.1
Total		35.0	42.5	36.7	105.7	98.1	35.5	353.5
Lodgepole pine 3/	3.1- 3.9	25.3	31.2	26.9	92.3	118.2	52.2	346.1
	4.0- 4.9	22.7	25.0	15.2	36.1	34.5	10.9	144.4
	5.0- 5.9	4.3	9.2	6.7	16.2	13.0	4.9	54.3
	6.0- 6.9	6.3	7.8	5.0	8.1	10.8	5.7	43.7
	7.0- 7.9	.8	1.4	2.6	6.7	5.0	1.2	17.7
	8.0-11.9	2.8	6.3	3.3	8.6	9.5	3.4	33.9
	12.0-15.9	1.1	.4	.6	1.2	1.0	.4	4.7
	16.0-19.9	0	.3	.2	.7	.8	.2	2.2
	20.0+	0	0	0	.3	0	.5	.8
Total		63.3	81.6	60.4	170.2	192.8	79.5	647.8

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 9—Product potential of logging residue (wood only) by gross and net volume, live and dead or cull, and by stratum[1]

Stratum	Product potential	Gross volume			Net volume		
		Live	Dead or cull	Total	Live	Dead or cull	Total
		Cubic feet per acre					
Public:							
Clearcut							
	Fiber	353	848	1201	284	347	631
	Post or pole	232	15	247	232	15	247
	House or sawlog	107	18	125	107	18	125
Total		692	881	1573	623	380	1003
Partial cut							
	Fiber	198	961	1159	154	356	510
	Post or pole	97	13	110	94	12	106
	House or sawlog	93	27	120	87	26	113
Total		388	1001	1389	335	394	729
Private 2/							
	Fiber	165	682	847	135	258	393
	Post or pole	98	6	104	98	5	103
	House or sawlog	57	4	61	57	4	61
Total		320	692	1012	290	267	557
Lodgepole pine 3/							
	Fiber	201	824	1025	176	412	588
	Post or pole	167	24	191	161	22	183
	House or sawlog	62	20	82	59	18	77
Total		430	868	1298	396	452	848

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 10—Distribution of logging residue by slope and distance-to-road class and by stratum[1]

Stratum	Percent slope	Distance to road (feet) 0-500	501-1,000	1,100	Total
		Percent			
Public:					
Clearcut	0-35	64.4	6.0	0.2	70.6
	36+	21.4	7.6	.4	29.4
Total		85.8	13.6	.6	100.0
Partial cut	0-35	50.3	17.7	2.3	70.3
	36+	20.4	5.6	3.7	29.7
Total		70.7	23.3	6.0	100.0
Private 2/	0-35	54.9	16.6	2.6	74.1
	36+	13.4	10.5	2.0	25.9
Total		68.3	27.1	4.6	100.0
Lodgepole pine 3/	0-35	74.0	13.2	1.2	88.4
	36+	9.6	2.0	.0	11.6
Total		83.6	15.2	1.2	100.0

1/ Includes residue in large piles which are usually, but not always, adjacent to a road.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Ratios for estimating residue volume developed in this report have a variety of uses. A major use of these data will be for estimating the volume of residue expected from timber harvest activities within a uniquely defined supply zone. The following is a hypothetical example of using data in this report to generate an estimate of the volume of residue for a specific location.

In this example, an estimate of annual residue volume is needed for a feasibility study of a proposed wood-fired power generation facility in Columbia Falls, Montana. Figure 7 shows the proposed supply zone for this example. The boundaries are based on existing transportation systems, timber harvest patterns, and an assumed cost-effective haul distance for residue of 75 miles. Although some residue outside the supply zone may be cheaper to recover than some within the zone, no attempt is made to account for it in this example. Both wood and bark residue is considered acceptable as fuel for the proposed facility.

Two types of data are needed to estimate residue volume for the supply zone. These are (1) annual harvest volume or acreage for each stratum within the supply zone, and (2) appropriate residue ratios corresponding to the strata identified above. Harvest volumes must be determined from available timber harvest records. For this example, the ratio for net residue volume (wood and bark) is taken from table 1.

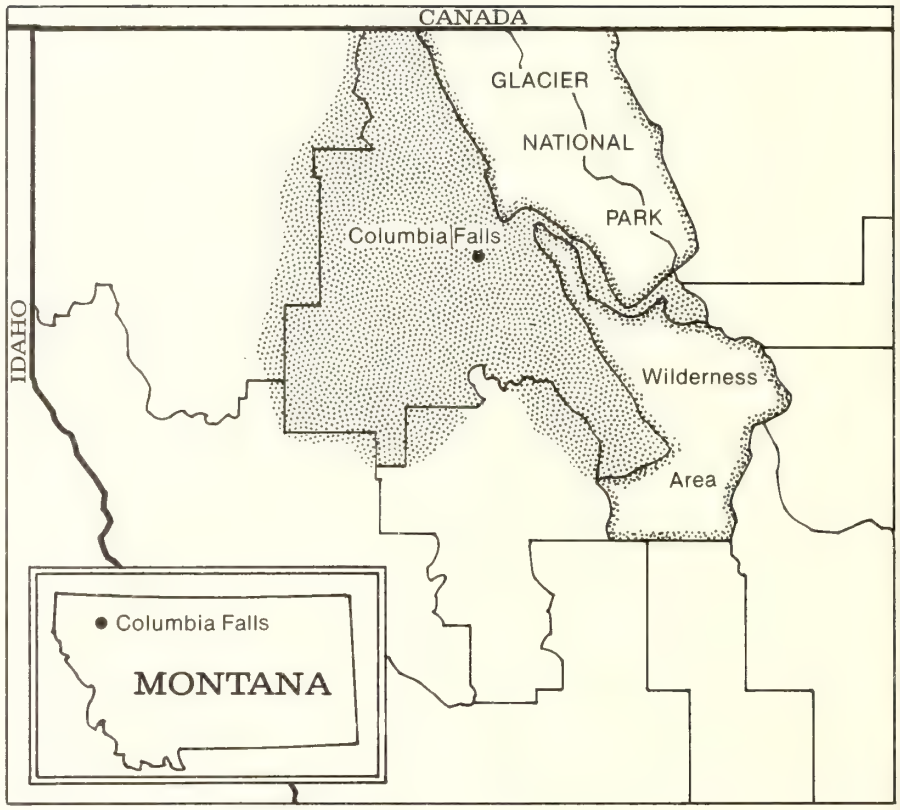


Figure 7.—Supply zone for a hypothetical wood-using facility located at Columbia Falls, Montana.

Shown below are the harvest volumes and residue ratios for the hypothetical example described.

Stratum	Annual harvest volume	Ratio of residue volume to harvest volume
	MBF	*CF/MBF*
Public:		
Clearcut	26,620	95
Partial cut	51,674	103
Private	93,424	137
Lodgepole pine	60,871	107

Volume of annual residue for the example can be estimated by multiplying the figures shown above as follows:

Public (clearcut)	26,620 × 95 =	2,528,900 cubic feet
Public (partial cut)	51,674 × 103 =	5,322,422 cubic feet
Private	93,424 × 137 =	12,799,088 cubic feet
Lodgepole pine	60,871 × 107 =	6,513,197 cubic feet
Total		27,163,607 cubic feet

Precision of Results

These computations show the annual residue volume for the supply zone in this hypothetical situation to be approximately 27 million cubic feet. The 27 million cubic feet of residue does not translate into an equivalent volume available for use. Other factors, such as future harvest levels, competition for available supplies, management objectives, and cost considerations play an important part in determining the amount of residue available for energy conversion. It is the responsibility of the analyst to determine this, but the above estimate provides a good baseline for a feasibility study.

The data in this report represent a new level of information on logging residue in Montana and issues related to site-specific analyses. These data provide a basis not previously available for assessing logging residue, but they do have limitations.

Table 11 gives the relevant statistical elements for determining precision of study results.

The indices of precision used here are based on gross wood volume of residue in cubic feet per acre (CF/AC), because the CF/AC volume of residue is the primary estimate provided by study measurements. Indices for CF/MBF ratios are not provided because they use timber harvest information provided by land owners. If errors in timber harvest volume exist, they are unknown.

Table 12 gives the range of study data for selected characteristics. This information is included to provide additional insight into the application of study results. It may also be useful if application is intended for areas beyond the scope of this report, for example, if the supply zone for a selected site includes geographic areas outside the boundaries of this study. If data in this report are the only available source, the information in table 12 may help determine their usefulness, but application should be restricted to the range of data indicated in table 12. The level of accuracy associated with the results of this report does not apply to extensions beyond the scope of the study.

Table 11—Statistical information for determining sampling precision by stratum

Stratum	Number of samples	Average gross volume (wood)	Standard error of the mean
		- - - Cubic feet per acre - - -	
Public:			
Clearcut	25	2021	215.3
Partial cut	35	1578	136.7
Private 1/	35	1345	148.4
Lodgepole pine 2/	25	1816	205.4

1/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

2/ Samples were selected from all harvest methods and ownership classes.

Table 12—Range of study data for stand age, harvest volume, area cut, and residue volume, by stratum

Stratum	Sample characteristics			
	Stand age	Harvest volume	Area cut	Net wood residue volume
	Years	Thousand board feet per acre	Acres	Cubic feet per acre
Public:				
Clearcut	70-200	4-48	5-34	473-2816
Partial cut	60-200	1-48	5-282	185-2061
Private 1/	50-300	2-22	10-448	139-2624
Lodgepole pine 2/	70-180	1-29	8-230	341-2841

1/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

2/ Samples were selected from all harvest methods and ownership classes.

Acknowledgments

This study was made possible by financial support from the U.S. Department of Energy, which had previously supported a study of logging residue in Idaho, Oregon, and Washington. The department joined the USDA Forest Service in recognizing the need to provide similar information for Montana.

The prompt and complete responses of private companies and public agencies to the inquiries of researchers contributed significantly to the success of the study.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 mile = 1.609 kilometers
1 acre = 0.405 hectare
1 cubic foot = 0.0283 cubic meter (stere)
1 pound = 0.454 kilogram
1 ton = 0.907 metric ton
1 British thermal unit (Btu) = 1,055.87 joules

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Appendix

Glossary[1]

Clearcut A harvest method in which all, or nearly all, of the trees in a stand of timber are cut in one operation.

Cutover area Synonymous with sample unit or sample area; the area encompassing a single harvest operation (example: a clearcut).

Diameter Diameter of residue pieces measured inside the bark (d.i.b.) at the point residue intersects a line transect.

Harvest volume Net scaled volume of timber removed from a cutover area during harvesting, expressed in thousand board feet (Scribner log scale) per acre (MBF/AC).

Line transect A vertical sampling plane with no width, along which all intersecting residue pieces are measured.

Logging residue

General All down and dead woody material existing on an area after timber harvest is completed.

Specific All logging residue (as defined above) 3.01 inches and larger inside bark (d.i.b.) and 1.0 foot and longer in length, including limbs, slabs, and splinters.

MBF 1,000 board feet of logs, a measure of the volume of timber harvested.

Owner class

Private Lands owned by private individuals, forest industries, or other corporations.

Public Lands owned by the public or managed by a public agency.

Partial cut A harvest method in which portions of a stand of timber are cut during a number of entries over time; precommercial thinnings are not included.

Product potential Classification of residue material as to its potential to yield (1) house or sawlog, (2) post or pole, and (3) fiber only.

Residue volume

Gross Volume of a piece of residue measured only by its external dimensions; includes rot, cracks, and missing parts.

Net The usable portion of a piece of residue; for this report usability is based on physical chippability of the material.

Chippability Condition of residue sound enough to be physically handled and capable of producing usable chips; includes residue exhibiting early stages of wet or dry rot.

Live Residue from trees that were alive before they were cut or knocked down during harvest.

Dead Residue from trees or portions of trees that were dead before harvest.

Cull Residue from trees that were cull (less than 25 percent sound) at the time of harvest.

Stratum A category of timber harvest area defined for this study by ownership class, harvest method, and forest type.

Supply zone A uniquely defined area containing a timber determined to be potentially available for a processing facility.

YUM (or PUM) piles Terms used by the USDA Forest Service for large piles of residue that have been yarded or bulldozed to a common location; if the residue has been piled with some degree of uniformity it is referred to as a PUM (piled unmerchantable material); otherwise, the term YUM (Yarded unmerchantable material) is used.

[1]Terms and abbreviations are defined as they are used in this report.

Wood Density and Heating Values for Selected Species

Species	Density (dry weight)[2] *(Pounds per cubic foot)*	Higher heating values (dry weight)[3] *(Btu per pound)*
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	28	9,050
Western larch (*Larix occidentalis* Nutt.)	30	8,510
Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.)	24	9,100
Lodgepole pine (*Pinus contorta* Dougl. ex Loud)	24	8,730
Western white pine (*Pinus monticola* Dougl. ex D. Don.)	22	—
Spruces (*Picea* spp.)	22	—
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	26	8,260
True firs (*Abies* spp.)	23	—
Western redcedar (*Thuja plicata* Donn. ex D. Don.)	19	9,700
Aspen (*Populus tremuloides* Michx.)	22	—
Red alder (*Alnus rubra* Bong.)	23	8,000
Black cottonwood (*Populus trichocarpa* (Torr. & Gray)	19	8,510

[2]U.S. Forest Products Laboratory (1974).

[3]Arola (1976); Bergvall and others (1978).

Table 13—Gross volume (wood only) of live logging residue by diameter and length classes and by stratum 1/

Stratum	Small end diameter	Length (feet)						
		1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Cubic feet per acre						
Public:								
Clearcut	3.1- 3.9	7	16	24	91	124	60	322
	4.0- 4.9	9	11	8	29	36	9	102
	5.0- 5.9	3	8	8	20	10	5	54
	6.0- 6.9	14	8	4	18	10	11	65
	7.0- 7.9	1	2	5	7	4	3	22
	8.0-11.9	4	7	15	20	9	7	62
	12.0-15.9	8	2	8	6	14	0	38
	16.0-19.9	4	0	0	9	0	0	13
	20.0+	8	6	0	0	0	0	14
Total		58	60	72	200	207	95	692
Partial cut	3.1- 3.9	4	8	8	40	51	28	139
	4.0- 4.9	2	5	3	16	14	8	48
	5.0- 5.9	1	2	3	9	7	4	26
	6.0- 6.9	4	3	2	7	6	12	34
	7.0- 7.9	0	1	1	1	3	1	7
	8.0-11.9	2	5	3	12	7	10	39
	12.0-15.9	11	5	3	18	8	0	45
	16.0-19.9	8	0	0	11	2	2	23
	20.0+	0	7	7	4	9	0	27
Total		32	36	30	118	107	65	388
Private 2/	3.1- 3.9	5	7	9	36	61	31	149
	4.0- 4.9	2	4	4	18	14	3	45
	5.0- 5.9	0	2	4	6	5	0	17
	6.0- 6.9	1	4	2	8	3	1	19
	7.0- 7.9	0	3	0	5	2	2	12
	8.0-11.9	6	6	5	10	4	2	33
	12.0-15.9	8	0	4	8	3	0	23
	16.0-19.9	4	0	4	6	4	0	18
	20.0+	0	0	0	0	4	0	4
Total		26	26	32	97	100	39	320
Lodgepole pine 3/	3.1- 3.9	8	12	12	51	98	47	228
	4.0- 4.9	6	9	6	26	20	5	72
	5.0- 5.9	3	5	4	11	8	3	34
	6.0- 6.9	2	5	4	4	5	3	23
	7.0- 7.9	1	2	2	5	4	1	15
	8.0-11.9	4	7	4	10	8	3	36
	12.0-15.9	5	0	2	4	0	0	11
	16.0-19.9	0	4	0	3	4	0	11
	20.0+	0	0	0	0	0	0	0
Total		29	44	34	114	147	62	430

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 14—Gross volume (wood only) of dead or cull logging residue by diameter and length classes and by stratum 1/

Stratum	Small end diameter	Length (feet)						
		1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Cubic feet per acre						
Public:								
Clearcut	3.1- 3.9	5	8	7	18	19	23	80
	4.0- 4.9	11	11	8	14	17	14	75
	5.0- 5.9	4	9	5	19	15	9	61
	6.0- 6.9	10	8	8	21	29	15	91
	7.0- 7.9	2	4	8	15	12	8	49
	8.0-11.9	15	27	19	56	58	38	213
	12.0-15.9	4	14	11	32	27	33	121
	16.0-19.9	0	0	17	34	35	18	104
	20.0+	0	8	0	16	49	14	87
Total		51	89	83	225	261	172	881
Partial cut	3.1- 3.9	5	7	5	26	38	53	134
	4.0- 4.9	8	10	4	21	26	40	109
	5.0- 5.9	2	8	7	14	17	17	65
	6.0- 6.9	4	6	7	26	31	41	115
	7.0- 7.9	7	5	4	21	27	11	75
	8.0-11.9	9	14	17	49	86	52	227
	12.0-15.9	2	9	6	30	27	39	113
	16.0-19.9	0	0	2	12	27	45	86
	20.0+	0	6	0	27	23	21	77
Total		37	65	52	226	302	319	1001
Private 2/	3.1- 3.9	6	7	6	16	21	11	67
	4.0- 4.9	7	8	5	14	15	11	60
	5.0- 5.9	4	5	2	15	10	5	41
	6.0- 6.9	4	7	7	19	17	7	61
	7.0- 7.9	0	3	6	18	8	3	38
	8.0-11.9	5	17	16	40	37	27	142
	12.0-15.9	1	14	8	28	32	20	103
	16.0-19.9	2	4	5	8	27	8	54
	20.0+	15	25	14	13	27	32	126
Total		44	90	69	171	194	124	692
Lodgepole pine 3/	3.1- 3.9	10	10	11	41	51	43	166
	4.0- 4.9	18	21	13	27	42	24	145
	5.0- 5.9	4	11	9	23	24	13	84
	6.0- 6.9	12	13	11	18	37	32	123
	7.0- 7.9	1	3	8	20	21	5	58
	8.0-11.9	11	24	13	46	59	24	177
	12.0-15.9	4	6	6	11	12	9	48
	16.0-19.9	0	0	4	17	13	3	37
	20.0+	0	0	0	15	0	15	30
Total		60	88	75	218	259	168	868

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 15—Net volume (wood only) of live logging residue by diameter and length classes and by stratum 1/

Stratum	Small end diameter	Length (feet) 1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Cubic feet per acre						
Public:								
Clearcut	3.1- 3.9	7	16	23	90	123	57	316
	4.0- 4.9	7	9	8	27	35	8	94
	5.0- 5.9	3	6	8	18	9	5	49
	6.0- 6.9	9	6	3	17	10	10	55
	7.0- 7.9	1	1	5	4	4	3	18
	8.0-11.9	2	4	11	18	9	7	51
	12.0-15.9	4	2	4	6	7	0	23
	16.0-19.9	1	0	0	10	0	0	11
	20.0+	3	3	0	0	0	0	6
Total		37	47	62	190	197	90	623
Partial cut	3.1- 3.9	4	7	7	38	48	27	131
	4.0- 4.9	2	5	3	16	13	7	46
	5.0- 5.9	1	2	2	8	6	3	22
	6.0- 6.9	3	2	2	5	5	11	29
	7.0- 7.9	0	1	1	1	2	1	6
	8.0-11.9	2	4	2	10	6	10	34
	12.0-15.9	10	3	1	13	7	0	34
	16.0-19.9	6	0	0	6	1	1	14
	20.0+	0	6	6	4	3	0	19
Total		28	30	24	102	91	60	335
Private 2/	3.1- 3.9	5	7	9	36	60	31	148
	4.0- 4.9	2	4	4	18	13	3	44
	5.0- 5.9	0	2	4	6	5	0	17
	6.0- 6.9	1	3	2	7	3	1	17
	7.0- 7.9	0	2	0	5	2	2	11
	8.0-11.9	4	5	5	8	4	2	28
	12.0-15.9	7	0	3	3	1	0	14
	16.0-19.9	2	0	4	2	0	0	8
	20.0+	0	0	0	0	3	0	3
Total		21	23	31	85	91	39	290
Lodgepole pine 3/	3.1- 3.9	6	12	10	48	95	45	216
	4.0- 4.9	6	8	5	24	19	5	67
	5.0- 5.9	2	4	3	11	7	2	29
	6.0- 6.9	2	3	4	3	4	3	19
	7.0- 7.9	1	2	2	4	4	1	14
	8.0-11.9	3	7	4	8	6	3	31
	12.0-15.9	5	0	1	4	0	0	10
	16.0-19.9	0	3	0	3	4	0	10
	20.0+	0	0	0	0	0	0	0
Total		25	39	29	105	139	59	396

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 16—Net volume (wood only) of dead or cull logging residue by diameter and length classes and by stratum 1/

Stratum	Small end diameter	Length (feet) 1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Cubic feet per acre						
Public:								
Clearcut	3.1- 3.9	3	5	4	12	15	20	59
	4.0- 4.9	5	7	6	10	13	11	53
	5.0- 5.9	1	4	3	11	9	6	34
	6.0- 6.9	2	3	5	12	15	8	45
	7.0- 7.9	0	2	4	9	8	3	26
	8.0-11.9	3	5	6	26	25	18	83
	12.0-15.9	3	1	3	14	11	12	44
	16.0-19.9	0	0	2	8	13	5	28
	20.0+	0	2	0	0	6	1	9
Total		17	29	33	102	115	84	380
Partial cut	3.1- 3.9	2	4	3	15	20	34	78
	4.0- 4.9	3	4	2	12	15	24	60
	5.0- 5.9	0	4	4	7	7	6	28
	6.0- 6.9	1	2	3	9	14	18	47
	7.0- 7.9	1	2	2	7	7	7	26
	8.0-11.9	2	4	6	17	30	22	81
	12.0-15.9	0	3	3	8	5	10	29
	16.0-19.9	0	0	0	3	8	16	27
	20.0+	0	2	0	6	2	8	18
Total		9	25	23	84	108	145	394
Private 2/	3.1- 3.9	3	4	3	10	13	7	40
	4.0- 4.9	3	3	2	8	8	5	29
	5.0- 5.9	1	2	1	8	6	3	21
	6.0- 6.9	0	2	3	8	7	3	23
	7.0- 7.9	0	1	2	6	4	2	15
	8.0-11.9	1	5	7	13	16	10	52
	12.0-15.9	0	5	3	7	7	5	27
	16.0-19.9	1	1	1	1	8	1	13
	20.0+	5	16	5	3	15	3	47
Total		14	39	27	64	84	39	267
Lodgepole pine 3/	3.1- 3.9	6	7	7	30	35	32	117
	4.0- 4.9	9	13	8	17	27	16	90
	5.0- 5.9	1	6	5	12	15	7	46
	6.0- 6.9	5	6	8	9	19	14	61
	7.0- 7.9	0	2	3	11	13	2	31
	8.0-11.9	4	8	7	23	22	7	71
	12.0-15.9	4	3	1	4	3	1	16
	16.0-19.9	0	0	3	1	6	1	11
	20.0+	0	0	0	9	0	0	9
Total		29	45	42	116	140	80	452

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 17—Number of live pieces of logging residue per acre, by diameter and length classes and by stratum 1/

Stratum	Small end diameter	Length (feet)						
		1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Number of pieces per acre						
Public:								
Clearcut	3.1- 3.9	10.3	23.0	26.2	85.2	101.9	37.1	283.7
	4.0- 4.9	8.5	7.9	6.5	19.3	20.2	3.7	66.1
	5.0- 5.9	1.8	4.0	4.0	9.0	3.7	1.5	24.0
	6.0- 6.9	5.8	3.3	1.5	6.4	3.5	1.8	22.3
	7.0- 7.9	.4	.4	1.4	1.7	1.0	.5	5.4
	8.0-11.9	.8	1.1	2.3	3.3	1.4	.5	9.3
	12.0-15.9	.7	.3	.7	.4	.9	0	3.0
	16.0-19.9	.3	0	0	.4	0	0	.7
	20.0+	.3	.3	0	0	0	0	.6
Total		28.9	40.3	42.6	125.7	132.6	45.0	415.1
Partial cut	3.1- 3.9	5.5	10.5	9.6	38.7	39.4	13.6	117.4
	4.0- 4.9	2.2	4.1	2.6	11.3	7.5	3.0	30.7
	5.0- 5.9	.5	1.3	1.3	3.9	2.3	1.1	10.4
	6.0- 6.9	1.3	1.0	.8	2.4	1.3	1.6	8.4
	7.0- 7.9	0	.4	.5	.5	.6	.1	2.1
	8.0-11.9	.4	.9	.4	2.1	.9	1.0	5.7
	12.0-15.9	1.0	.3	.2	1.4	.7	0	3.6
	16.0-19.9	.4	0	0	.6	.2	.1	1.3
	20.0+	0	.2	.2	.2	.1	0	.7
Total		11.4	18.7	15.6	61.1	53.0	20.5	180.3
Private 2/	3.1- 3.9	8.1	9.5	11.0	33.6	46.5	16.6	125.3
	4.0- 4.9	2.3	3.0	3.4	10.9	7.6	1.3	28.5
	5.0- 5.9	.3	1.4	2.0	2.7	1.6	.1	8.1
	6.0- 6.9	.6	1.4	.6	2.8	.7	.2	6.3
	7.0- 7.9	0	.7	0	1.1	.3	.5	2.6
	8.0-11.9	1.2	.6	.6	1.4	.6	.4	4.8
	12.0-15.9	.7	0	.3	.5	.2	0	1.7
	16.0-19.9	.1	0	.2	.3	.1	0	.7
	20.0+	0	0	0	0	.2	0	.2
Total		13.3	16.6	18.1	53.3	57.8	19.1	178.2
Lodgepole pine 3/	3.1- 3.9	10.5	16.8	14.4	52.0	79.1	30.8	203.6
	4.0- 4.9	5.7	7.6	4.7	17.7	12.8	2.1	50.6
	5.0- 5.9	1.9	3.1	1.8	5.5	3.7	1.2	17.2
	6.0- 6.9	.8	2.0	1.3	1.6	1.5	.4	7.6
	7.0- 7.9	.4	.6	.5	1.3	.6	.2	3.7
	8.0-11.9	.6	1.5	1.1	1.8	1.1	.4	6.5
	12.0-15.9	.5	0	.3	.5	0	0	1.3
	16.0-19.9	0	.2	0	.2	.2	0	.6
	20.0+	0	0	0	0	0	0	0
Total		20.4	31.9	24.1	80.6	99.0	35.1	291.1

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 18—Number of dead or cull pieces of logging residue per acre, by diameter and length of classes and by stratum 1/

Stratum	Small end diameter	Length (feet)						
		1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32.0+	Total
	Inches	Number of pieces per acre						
Public:								
Clearcut	3.1- 3.9	7.7	11.4	7.0	14.1	11.2	9.1	60.5
	4.0- 4.9	11.2	9.4	6.8	10.7	10.1	5.4	53.6
	5.0- 5.9	2.7	4.6	2.3	8.4	5.1	2.6	25.7
	6.0- 6.9	4.2	3.4	2.9	7.6	9.0	3.8	30.9
	7.0- 7.9	.8	1.2	2.1	3.8	2.8	1.2	11.9
	8.0-11.9	2.7	5.1	2.9	8.3	8.3	4.2	31.6
	12.0-15.9	.3	1.2	.8	2.9	2.2	2.0	9.5
	16.0-19.9	0	0	.9	1.8	1.5	.9	5.1
	20.0+	0	.1	0	.5	1.4	.5	2.5
Total		29.6	36.5	25.7	58.1	51.6	29.8	231.3
Partial cut	3.1- 3.9	6.3	10.1	5.9	26.1	30.7	25.2	104.2
	4.0- 4.9	7.5	7.5	3.7	14.7	13.9	13.8	61.1
	5.0- 5.9	1.2	4.2	3.8	5.9	6.4	5.2	26.7
	6.0- 6.9	1.9	2.4	2.9	9.2	9.0	7.8	33.2
	7.0- 7.9	2.0	1.7	.9	5.1	6.4	2.3	18.4
	8.0-11.9	2.0	2.8	3.0	7.5	12.3	5.9	33.5
	12.0-15.9	.3	.9	.4	2.7	2.4	2.3	8.6
	16.0-19.9	0	0	.2	.7	1.2	1.6	3.7
	20.0+	0	.1	0	.8	.6	.4	1.9
Total		21.1	29.7	20.8	72.3	82.9	64.5	291.3
Private 2/	3.1- 3.9	8.9	8.4	6.0	15.8	13.0	4.1	56.2
	4.0- 4.9	7.0	6.5	4.3	9.2	6.7	3.1	36.8
	5.0- 5.9	2.1	2.0	.8	6.7	4.0	1.8	17.5
	6.0- 6.9	1.8	3.0	2.4	6.6	4.8	1.3	19.9
	7.0- 7.9	.2	.9	1.4	4.2	2.0	.7	9.4
	8.0-11.9	1.0	3.0	2.5	6.7	5.4	3.1	21.7
	12.0-15.9	.1	1.3	.7	2.4	2.5	1.3	8.3
	16.0-19.9	.2	.2	.2	.4	1.1	.4	2.6
	20.0+	.4	.6	.3	.4	.6	.6	2.9
Total		21.7	47.6	18.6	52.4	40.3	16.4	175.3
Lodgepole pine 3/	3.1- 3.9	14.8	14.4	12.5	40.3	39.1	21.4	142.5
	4.0- 4.9	17.0	17.4	10.5	18.4	21.7	8.8	93.8
	5.0- 5.9	2.4	6.1	4.9	10.7	9.3	3.7	37.1
	6.0- 6.9	5.5	5.8	3.7	6.5	9.3	5.3	36.1
	7.0- 7.9	.4	.8	2.1	5.4	4.4	1.0	14.0
	8.0-11.9	2.2	4.8	2.2	6.8	8.4	3.0	27.4
	12.0-15.9	.6	.4	.3	.7	1.0	.4	3.4
	16.0-19.9	0	.1	.2	.5	.6	.2	1.6
	20.0+	0	0	0	.3	0	.5	.8
Total		42.9	49.7	36.3	89.6	93.8	44.4	356.7

1/ Does not include residue in large piles.

2/ Samples were selected from all harvest methods; most samples were from partial-cut areas.

3/ Samples were selected from all harvest methods and ownership classes.

Table 19—Average net volume (wood and bark) of logging residue by area, owner class, and harvest method, per thousand board feet of timber harvest in Idaho, Oregon, and Washington

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per thousand board feet	
Idaho:		
National Forest	87	122
Other public	--	1/ 142
Private	--	T/ 109
Western Oregon:		
National Forest	47	2/ 136
Other public	52	93
Private	40	296
Western Washington		
National Forest	44	2/ 136
Other public	51	118
Private	37	140
Eastern Oregon		
Public	--	1/ 76
Private	--	T/ 80
Eastern Washington		
Public	--	1/ 96
Private	--	T/ 72

-- means not applicable.

1/ Samples selected randomly from all areas harvested since January 1, 1979; most samples were from partial-cut areas, the predominant practice in this stratum.

2/ An average for cutover areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Source: Howard 1981a.

Table 20—Average net volume (wood and bark) of logging residue by area, owner class, and harvest method in Idaho, Oregon, and Washington

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per acre	
Idaho:		
National Forest	2,182	1,701
Other public	--	1/ 1,182
Private	--	1/ 824
Western Oregon:		
National Forest	2,471	2/ 1,488
Other public	2,642	1,184
Private	2,070	1,537
Western Washington		
National Forest	2,497	2/ 1,488
Other public	2,110	895
Private	1,331	992
Eastern Oregon		
Public	--	1/ 553
Private	--	1/ 534
Eastern Washington		
Public	--	1/ 670
Private	--	1/ 394

-- means not applicable.

1/ Samples selected randomly from all areas harvested since January 1, 1979; most samples were from partial-cut areas, the predominant practice in this stratum.

2/ An average for cutover areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Source: Howard 1981a.

Howard, James O.; Fiedler, Carl E. Estimators and characteristics of logging residue in Montana. Res. Pap. PNW-321. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 29 p.

Ratios are presented for estimating volume and characteristics of logging residue in Montana. They relate cubic-foot volume of residue to thousand board feet of timber harvested and to acres harvested. Tables show gross and net volume of residue, with and without bark; by diameter and length classes; by number of pieces per acre; by percent soundness, by product potential, and by degree of slope and distance to roads.

Keywords: Residue estimation, residue measurements, slash, volume estimation, slash utilization, residue management, Montana.

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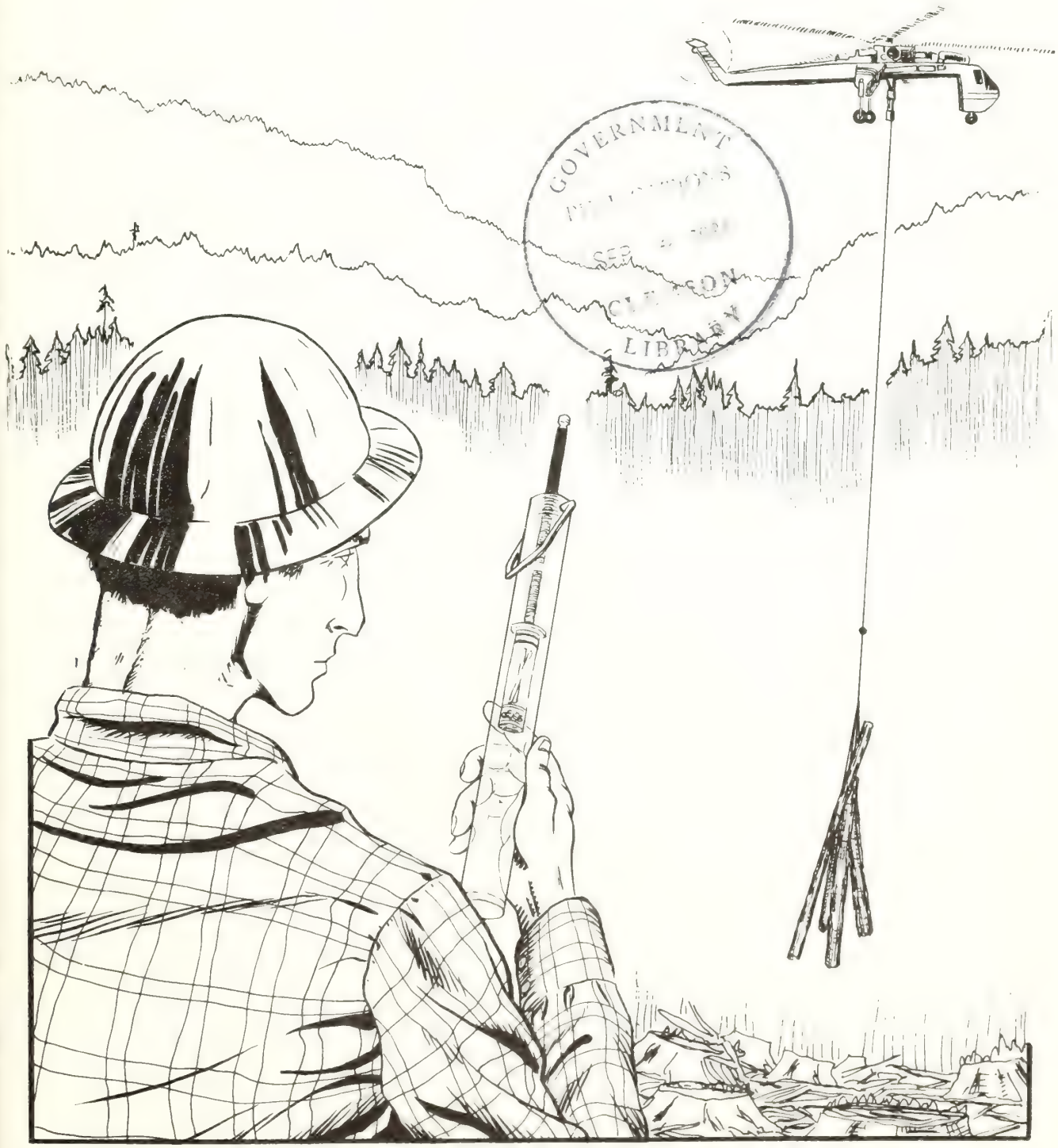
Estimating Tree Bole and Log Weights From Green Densities Measured With the Bergstrom Xylodensimeter

Dale R. Waddell, Michael B Lambert, and W. Y. Pong



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Abstract

Waddell, Dale R.; Lambert, Michael B; Pong, W. Y. Estimating tree bole and log weights from green densities measured with the Bergstrom xylodensimeter. Res. Pap. PNW-322. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 18 p.

The performance of the Bergstrom xylodensimeter, designed to measure the green density of wood, was investigated and compared with a technique that derived green densities from wood disk samples. In addition, log and bole weights of old-growth Douglas-fir and western hemlock were calculated by various formulas and compared with lifted weights measured with a load cell attached to a front-end loader. The Bergstrom xylodensimeter accurately measured green wood density and is useful for estimating log weights.

Keywords: Log measurements, boles, wood density, cubic volume measure, measuring equipment, old-growth stands.

Summary

Aerial logging of heavy material requires accurate estimates of load weight for safety and for economical production. Green wood density is an important element in estimating log and tree bole weight. This study was conducted to evaluate the Bergstrom xylodensimeter, an instrument consisting of a calibrated hydrometer and flotation chamber that measures the green density of an increment core. Results obtained with the xylodensimeter were compared with results using the standard wood disk technique. Log weights calculated from measured green densities multiplied by the volume of the log were compared with actual weights. Calculated weights of tree boles were also compared with lifted weights. Bias and accuracy statistics were also presented.

The study was conducted in the Wind River Experimental Forest, Gifford Pinchot National Forest, in southwest Washington; green density and log weights of both Douglas-fir and western hemlock were tested.

Results indicated acceptable values of bias and accuracy for many applications in aerial logging. Further refinements in methodology and additional research are recommended. Examples of how to apply the techniques are provided.

Introduction

In the last 20 years, there has been an emphasis in forestry on developing aerial logging systems including heavy-lift helicopters, balloons, and airships. They increase yarding efficiency through larger lift capacities, better access to remote timber, and less road construction. The result can be lower primary transportation costs per unit volume of timber with potentially less impact on the environment.

For most timber harvesting systems, a substantial increase in production rates can can be accomplished by the accurate estimation of log weights (Conway 1976, Dykstra 1975, Hartsough and others 1983). In cable yarding systems, the size of the cable line is often dictated by the weight of the heaviest logs in a sale unit. Poor estimates of load weights in aerial logging periodically result in aborts caused by overloading and in extra flight hours when payloads do not approach lift capacity; therefore, the larger the lift capacity of the airborne system and the higher the percentage of time spent transporting logs from the woods to the landing, the greater the requirement to accurately estimate the weight of the load.

Although accurate determination of log weights is critical to the success of aerial logging systems, estimation of log weights has received limited research attention. The need for accurate weights was recognized in the early 1960's when weight scaling and heavy-lift aerial logging attracted the interest of foresters.

Generally, the two variables required to provide an estimate of the weights of the whole bole or of segments are volume and green density (dry density plus moisture). This paper deals primarily with the measurement of green density and represents one step in a system that will eventually help solve various problems related to the prediction of weight.

The Bergstrom xylodensimeter[1] was designed to estimate the green density of wood in the field. Bergstrom developed the device after observing partially submerged logs in a millpond. He noted that logs with similar dimensions float at varying depths, presumably because of differences in green density. After investigating further, however, he found that others had noted that floating logs in millponds may not accurately reflect their density. He assumed that this was caused by uneven taper, sweep, crook, or other dimensional features of the log. He hypothesized that if a uniform sample from a log could be obtained, this problem might be overcome. He then constructed a portable device to measure the displacement of water in a plastic container when an increment core was submerged.

---

[1] The xylodensimeter ("xylo" meaning wood) was designed by Gary Bergstrom, presently working as a logging specialist, USDA Forest Service, Rogue River National Forest, Medford, Oregon.

The Bergstrom xylodensimeter consists of a hydrometer and a plastic cylinder (flotation chamber) containing water. The hydrometer is calibrated to house an increment core of a specific diameter and length (fig. 1). The hydrometer is constructed of thin-walled aluminum and plastic. An increment core is inserted in the hydrometer and then floated in the plastic cylinder filled with distilled water. Green density (pounds per cubic foot) is read directly from the waterline on the graduated scale of the hydrometer. The instrument has been tested and successfully calibrated with homogeneous materials of known densities. The measurement of the green density of wood, essentially a heterogeneous material, and its application to estimating log weights is the next logical step in the evaluation process.

This study was designed to answer three questions about the performance of the Bergstrom xylodensimeter as a tool for estimating log and bole weights:

1. How accurately can it measure the green density of wood in recently cut logs compared with standard wood disk techniques?

2. Can this measurement of green density, combined with the volume of the log, estimate the weight of logs accurately?

3. How well do models developed from measurements on a small subsample of trees predict the weights of boles for trees in the same stands and from different stands?

We conducted two field studies with the Bergstrom xylodensimeter, one in the summer of 1981 and the other in the summer of 1982. After qualitative evaluations were conducted in the 1981 study, structural changes were made on the hydrometer element (fig. 1) to provide an easier means of inserting fragile increment cores.

Objectives

Objectives were to estimate: (1) the accuracy and bias of the Bergstrom xylodensimeter in the measurement of green wood density, (2) the accuracy and bias of estimated log weights from calculated volumes and green densities measured with the Bergstrom xylodensimeter, and (3) the accuracy and bias of predicted tree bole weights from regression equations developed for one population of trees and applied to other populations.

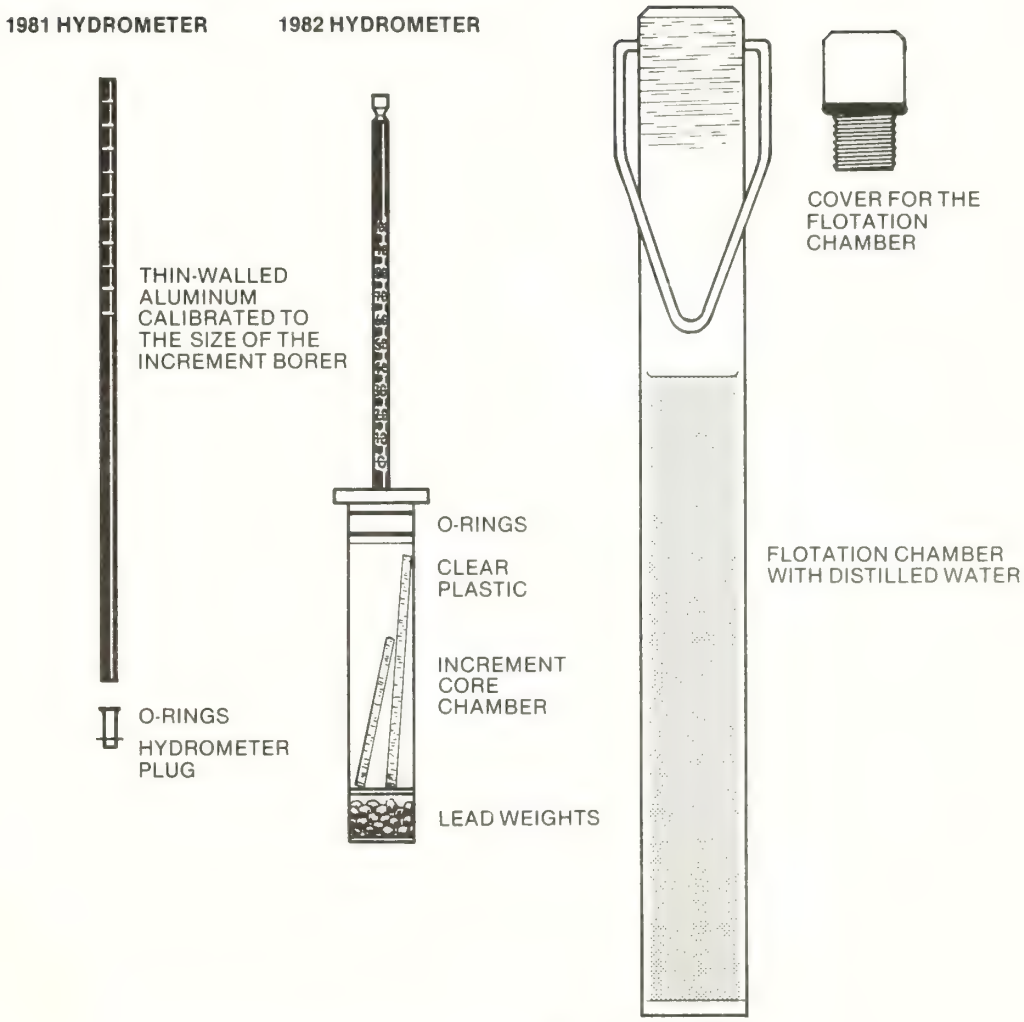


Figure 1.—A schematic of the Bergstrom xylodensimeter

Methods

Study Area

Four study plots (three 5-acre plots and one 20-acre plot) were selected in the Wind River Experimental Forest (Trout Creek Hill Unit) on the Gifford Pinchot National Forest, southwest Washington. The principal species in the area are old-growth Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock *(Tsuga heterophylla* (Raf.) Sarg.). Secondary species are western redcedar *(Thuja plicata* Donn ex D. Don) and true firs *(Abies* spp.).

Selection of Sample Trees

Study trees from the four plots were selected from old-growth merchantable Douglas-fir and western hemlock, ranging in diameter at breast height (DBH)[2] from 10 to 60 inches.[3] The total number of western hemlock and Douglas-fir on the four plots was 1,876. This includes the combination of all trees for both the 1981 and 1982 studies. Each tree was assigned a sequential number. After stratification by species and diameters, 30 trees of each species were randomly selected from three 5-acre plots (1981 sample; plots 1 to 3) and 50 trees per species from one 20-acre plot (1982 sample; plot 4) (table 1). Because of problems in the load cell during weighing, one western hemlock and one Douglas-fir tree were deleted from the 1981 sample, leaving 79 trees per species for the entire study.

[2] Diameter of tree bole at 4½ feet above ground level as measured on the uphill side of the tree

[3] Trees selected in the three 5-acre plots (1981 samples) were screened for major defects and external damage determined by a concurrent study of tree crowns. If defect or damage in a tree would jeopardize the safety of a tree climber, the tree was not selected.

Table 1—Distribution of 79 sample trees by species and diameter class, southwestern Washington

Diameter class 1/	1981, plots 1-3		1982, plot 4	
	Western hemlock	Douglas-fir	Western hemlock	Douglas-fir
Inches				
10.0-15.5	2	0	6	0
15.6-20.5	4	0	5	2
20.6-25.5	7	2	6	4
25.6-30.5	3	3	9	8
30.6-35.5	7	4	7	6
35.6-40.5	4	4	4	8
40.6-45.5	2	2	8	8
45.6-50.5	0	5	4	8
50.6-55.5	0	2	1	6
55.6-60.5	0	7	0	0
Total	29	29	50	50

1/ Diameter at breast height.

Trees were felled and bucked into segments with length restricted so that the weight of individual logs would not exceed the capacity of the front-end loader used to lift the logs for weighing. The bucking of logs began as a trial and error process until approximations of maximum log lengths could be established for a given diameter class. All logs were identified with coded tags after bucking.

Measuring Green Density by the Wood Disk Technique (1981 Sample)

Immediately after the felling operation, wood disks were cut from the large end of the butt log and at various intervals to the top of the bole (fig. 2). Four wedge-shaped pieces were cut radially along perpendicular diameters of each disk. Each wedge was divided into sapwood and heartwood zones. From each zone a sample, approximately 1.5 x 1.5 x 4 inches, was taken. These samples provided material for determining the radial profile of green density in the sapwood and heartwood

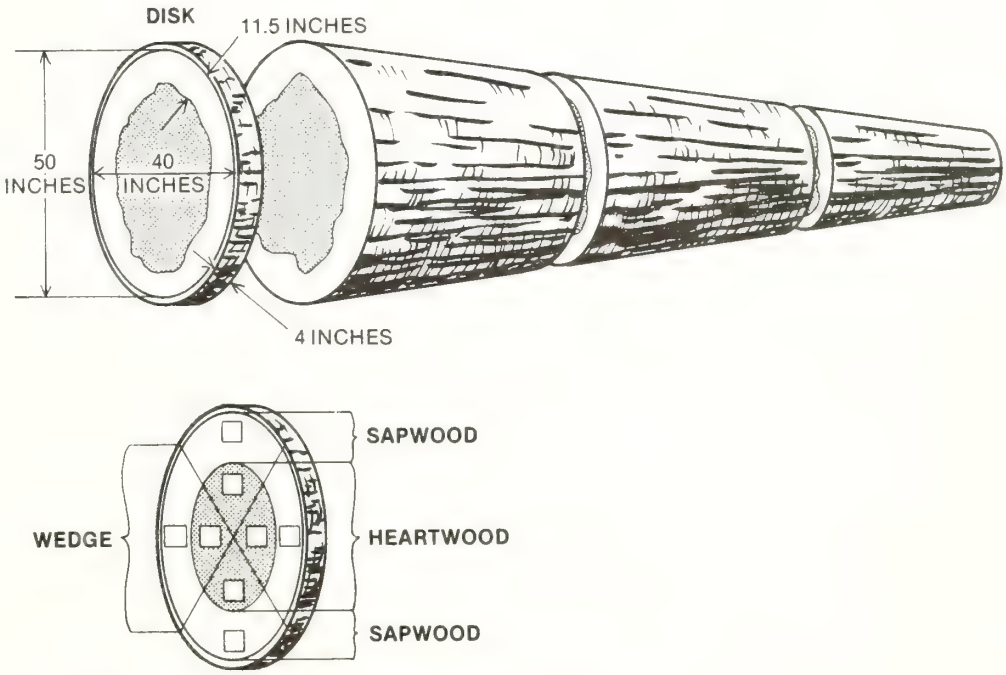


Figure 2.—The measurement of green density by the disk method

An example of a "weighted average green density" computation for a single disk.

Green density averages (four samples per component):
Sapwood component = 52 lb/ft^3.
Heartwood component = 48 lb/ft^3.
Volume calculation:
Volume (ft^3) = (π)(radius)^2(disk thickness)/1728.

Total wood volume in the disk	= (π)(45 inches/2)^2(4 inches)/1728
	= 3.68 ft^3.
Heartwood volume in the disk	= (π)(22 inches/2)^2(4 inches)/1728
	= 0.88 ft^3.
Sapwood volume in the disk	= 3.68 ft^3 − 0.88 ft^3
	= 2.80 ft^3.
Sapwood weight	= (52 lb/ft^3)(2.80 ft^3)
	= 145.60 lb.
Heartwood weight	= (48 lb/ft^3)(0.88 ft^3).
	= 42.24 lb.
Total weight	= 187.84 lb.
Weighted average green density	= 187.84 lb/3.68 ft^3
	= 51.04 lb/ft^3.

regions of the disk. Each density sample was labeled so that its location in the tree could be traced radially and longitudinally. The number of disks cut per tree depended on tree size and log length. Logs with small diameters had only one radial sample taken for each wedge-shaped section because of the lack of heartwood in logs of the upper crown. Samples were taken to the laboratory in sealed, tared containers for further analysis.

In the laboratory, the green weight of each sample was measured and the volume was determined by immersing the sample in water (Brown and others 1952). The green density of the sample was calculated by dividing the weight of the sample by its green volume. An average green density was computed for the four radial samples extracted from the sapwood and heartwood zones of the disk. A single weighted green density was then determined from volumetric proportions of sapwood to heartwood. An example is presented in figure 2.

Measuring Green Density With the Xylodensimeter (1981 and 1982 Samples)

After disk sampling (1981 samples), two increment cores were taken at each sample point (one core from above and one from below the disk sample). Volumetric proportions of sapwood to heartwood in the logs were duplicated in the cores by cutting them to a 6-inch length in approximately the same percentage, by volume, of the sapwood and heartwood components in the log. Two radial measurements were needed so that appropriate proportions of sapwood to heartwood could be applied to the core for each sample point; these were the diameter inside bark (DIB) and inches of sapwood (IOS). The DIB was measured from the cross section of the log at the sampling point (average of the long and short diameters). The IOS was measured directly from the extracted core.

The following equation provides the percentage of sapwood (%S) needed in the core to duplicate the proportion of sapwood in the log:

$$\%S = \frac{(DIB)^2 - ((DIB)-2(IOS))^2}{(DIB)^2}(100) = \frac{4(IOS)(DIB-IOS)}{(DIB)^2}(100). \qquad (1)$$

Equation 1 was programed into a calculator and was also presented as a series of curves for various combinations of DIB and IOS (fig. 3); for example, from either equation 1 or figure 3, a log with a 30-inch DIB and 3.3 inches of sapwood would have 39 percent sapwood.

The increment core was placed in a "core length cutter guide" and cut with a sharp knife to the correct length (fig. 4). The metal L-shaped device has a scale for percentage of sapwood inscribed on the surface. The heartwood to sapwood transition of the core was placed adjacent to the inscribed %S, as calculated from equation 1 or read from the curves, (fig. 3), and the core was cut flush at both ends of the guide. The process results in a 6-inch increment core with the same estimated ratio of heartwood to sapwood volume as that of the log.

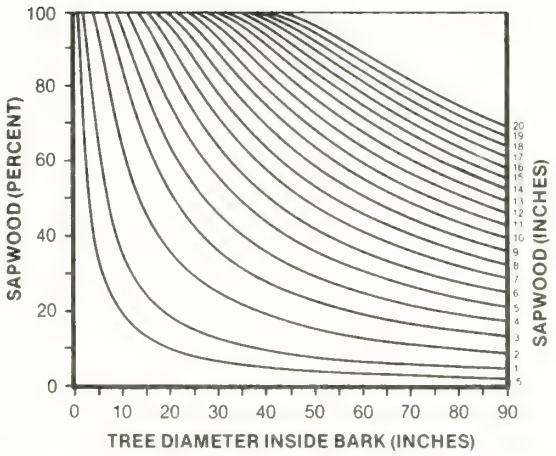


Figure 3.—Curves showing percentage of sapwood.

$$\text{Sapwood (percent)} = \frac{4(IOS)(DIB-IOS)}{(DIB)^2}(100)$$

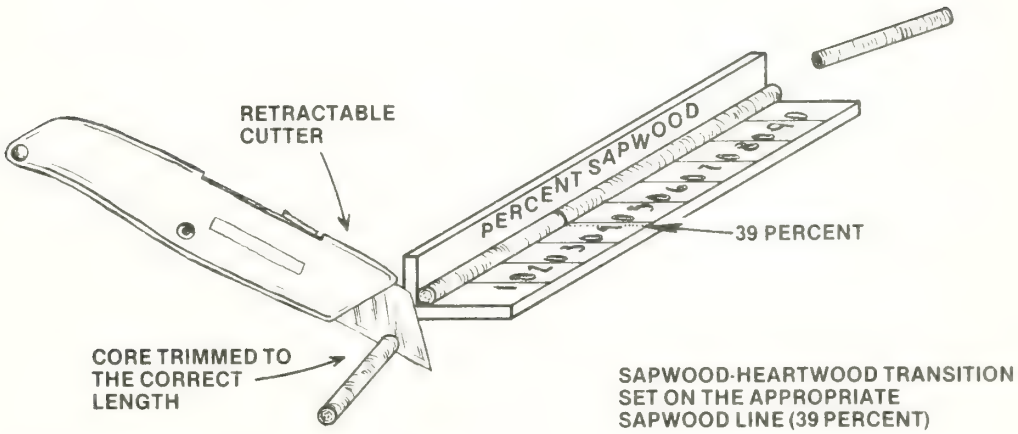

RETRACTABLE CUTTER
PERCENT SAPWOOD
39 PERCENT
CORE TRIMMED TO THE CORRECT LENGTH
SAPWOOD-HEARTWOOD TRANSITION SET ON THE APPROPRIATE SAPWOOD LINE (39 PERCENT)

Figure 4.—Core length cutter guide.

The core was then placed in the hydrometer and lowered into the water-filled flotation chamber (fig. 1). A reading taken at the intersection of the waterline with the graduated scale of the hydrometer gave the green density of the core. Figure 5 illustrates the procedure.

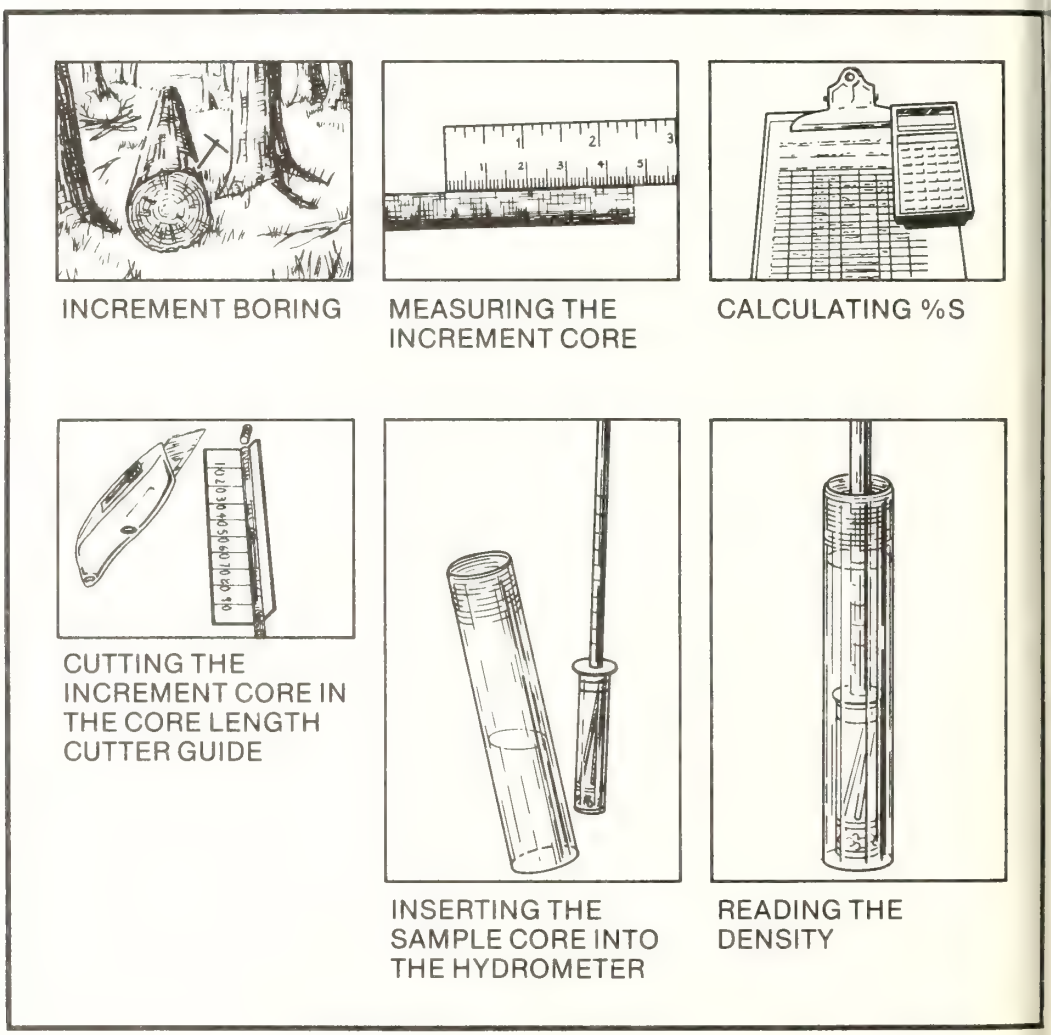

INCREMENT BORING
MEASURING THE INCREMENT CORE
CALCULATING %S
CUTTING THE INCREMENT CORE IN THE CORE LENGTH CUTTER GUIDE
INSERTING THE SAMPLE CORE INTO THE HYDROMETER
READING THE DENSITY

Figure 5.—The process of measuring green density with the Bergstrom xylodensimeter

Comparison of the Wood Disk Technique With the Xylodensimeter Technique (1981 Sample)

Estimates of green density by the wood disk technique were compared with estimates by the xylodensimeter in terms of the mean of the differences and the mean of the absolute differences for paired observations in both western hemlock and Douglas-fir. The comparison provided an estimate of bias (mean of the differences) and absolute error (mean of the absolute differences) for the xylodensimeter in terms of the values obtained from the wood disk measurement.

Calculating Log Weights From Densities Obtained With the Xylodensimeter (1982 Sample)

Each log was scaled for gross cubic volume after it was sampled for density. Log-end diameters (outside bark) were measured on the cross section of the log to the nearest (0.1) inch and the lengths to the nearest (0.1) foot. Volumes for Douglas-fir butt segments were calculated by Bruce's (1982) butt log equation:

$$V = CL(0.25D^2 + 0.75d^2); \quad (2)$$

for western hemlock butt segments by the sub-neiloid rule, for midsegments of both species by the Smalian rule, for top segments of both species by the two-end conic rule (Dilworth 1981):

sub-neiloid rule:

$$V = CL\ \frac{(D + d)^2}{2}\ ; \quad (3)$$

Smalian rule:

$$V = CL\ \frac{(D^2 + d^2)}{2}\ ; \quad (4)$$

two-end conic rule:

$$V = CL\ \frac{(d^2 + D^2 + Dd)}{3}\ ; \quad (5)$$

where:

V = volume of the log in cubic feet;
C = 0.005454 (unit conversion factor);
L = length of the log in feet;
D = average diameter outside bark for the large end of the log in inches; and
d = average diameter outside bark for the small end of the log in inches.

The end area of the log was used as the weighting factor to calculate a green density value for each log:

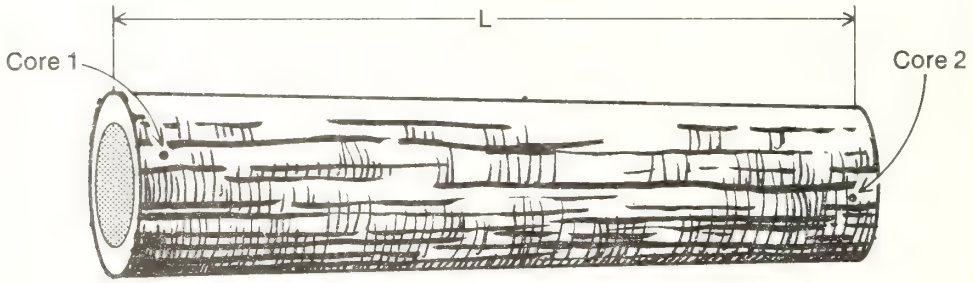
$$\text{Average green density} = \frac{(D)^2\,(K) + (d)^2\,(k)}{2\left[\frac{(D + d)}{2}\right]^2}\ ; \quad (6)$$

where:

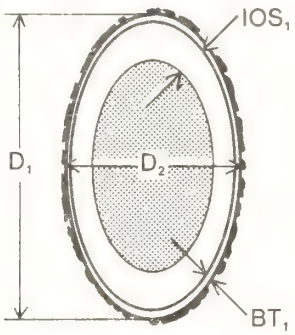
K = green density of the core measured at the large end of the log in pounds per cubic foot (lb/ft^3); and

k = green density of the core measured at the small end of the log in lb/ft^3.

Figure 6 illustrates a typical Douglas-fir butt log with various dimensions and densities. The calculated average green density for this particular log equals 38.0 lb/ft^3. The volume multiplied by the weighted green density equals the calculated weight (6,881 lb). Note that the bark is considered part of the gross wood volume and receives an average density value equal to that calculated for the wood. Log weights were not calculated from densities by the wood disk technique because of insufficient sampling points along the bole of each tree.



FACE AT CORE 1 (LARGE END)



FACE AT CORE 2 (SMALL END)

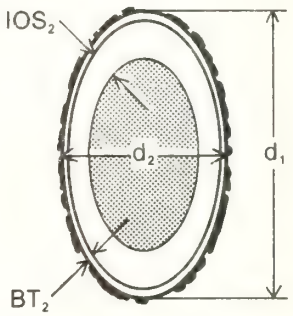


Figure 6.—A technique for calculating log weights with the Bergstrom xylodensimeter.

Measurements:

D_1 = longest diameter (DOB) = 50 inches.
D_2 = shortest diameter (DOB) = 40 inches.
Average diameter (D) = 45 inches.
BT_1 = single bark thickness = 2.5 inches.
BT_2 = single bark thickness = 2.25 inches.
d_1 = longest diameter (DOB) = 45 inches.
d_2 = shortest diameter (DOB) = 40 inches.
Average diameter (d) = 42.5 inches.
IOS_1 = inches of sapwood (large end of the log) = 2.25 inches.
Percentage of sapwood (see eq. 1) = 21.
Density reading of the large end = 39 lb/ft^3.
IOS_s = inches of sapwood (small end of the log) = 2 inches.
Percentage of sapwood = 20.
Density reading of the small end = 37 lb/ft^3.

Calculations:

Average density of the log = $\frac{(45)^2(39) + (42.5)^2(37)}{2[(45 + 42.5)/2]^2} = 38.09$ lb/ft^3.

L = log length = 17.8 feet.

Volume (eq. 2) = $(0.005454)(17.8)[(0.25)(45)^2 + (0.75)(42.5)^2]$
= 180.66 ft^3.

Calculated weight of the log = (180.66 ft^3)(38.09 lb/ft^3)
= 6,881 lb.

Measuring Log Weights (Lifted Weights) and Comparing Them With Calculated Weights (1981 Sample)

Each log was weighed by use of a load cell attached to a front-end loader. Weights of logs lifted by the load cell were compared with calculated weights in terms of bias and absolute error.

Calculating Bole Weights From Densities Measured With the Xylodensimeter (1982 Sample)

Sample trees of both species were divided into two random subsamples of 25 trees for model construction measurements and for model validation purposes (20-acre plot only). After felling, each tree was partitioned into a lower section (approximately one-third of the merchantable height) and an upper section (the remaining bole). The merchantable height was to a 6-inch top (DIB). Diameter outside bark (DOB) and bark thickness were measured in the lower section every 3 feet from the stump; DOB was measured with a diameter tape or steel calipers, and bark was measured with a steel ruler after it was chopped. An increment core was extracted every 6 feet and a modified Bergstrom xylodensimeter (fig. 1) was used to determine density of the extracted cores. This procedure produced a succession of diameter and density readings for the bole.

Volumes were calculated by the Smalian rule (eq. 4) for each 3-foot subsection and were converted to green weight by multiplying the values by an appropriate green density. The weights of all the 6-foot subsections were totaled for the weight of the lower bole.

The upper section of the merchantable bole was divided into eight equal subsections. Diameters outside bark and bark thickness were measured at each division. Increment cores were extracted for measurement of density at the fourth and sixth diameter locations (fig. 7).

The volumes of the upper subsections were calculated by Newton's formula (Dilworth 1981):

$$V = CL\,\frac{(d^2 + 4M^2 + D^2)}{6}; \qquad (7)$$

where:

M = diameter outside bark for the middle of the log in inches.

Because green density was not measured for each corresponding volume calculation (subsection), green density values were interpolated by calculating the change in green density as a function of length between actual density measurements (fig. 7). In the extreme upper bole, the green density at the sixth diameter location was used for the remaining subsection(s). The weights for each subsection were added to produce the weight for the upper bole. The lower and upper sections were then added together to determine the calculated bole weight.

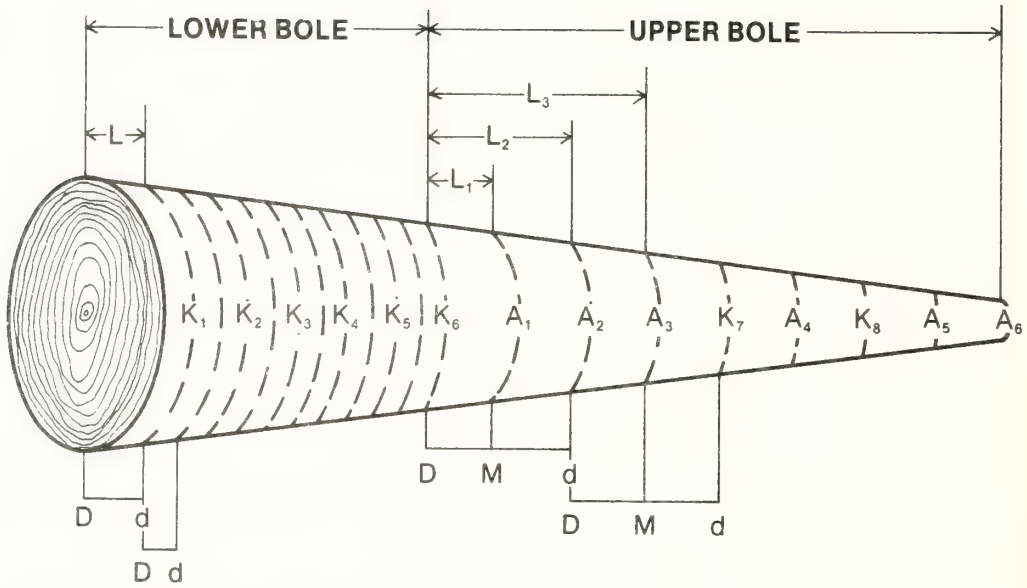


Figure 7.—Calculation of bole weights.

Lower bole:

Volume, Smalian $(V_l) = CL \frac{(D^2 + d^2)}{2}$.

Weight of a subsection $(W_l) = (V_l)(k_l)$.

Weight of the lower bole $= \sum_{i=1}^{n} (W_l)$.

Upper bole:

Interpolated green density $(A_1) = k_6 + \frac{(k_7 - k_6)}{L_3} (L_l)$.

Volume, Newton $(V_1) = \frac{(D^2 + 4M^2 + d^2)}{6} (C)\ (L_2)$.

Weight of a subsection $(W_1) = (V_1)(A_1)$.

Weight of the upper bole $= \sum_{i=1}^{n} (W_l)$.

Where:

D = diameter outside bark, large end.
M = diameter outside bark, middle.
d = diameter outside bark, small end.
C = 0.005454.
L = length of segment.
L_l = length in feet, i = 1, 2, . . . , n.
k_l = measured green density; i = 1, 2, . . . , n.
A_l = interpolated green density; i = 1, 2, . . . , n.
A_e = extrapolated green density; e = 5, 6.

Measuring Lifted Weights and Comparing Them With Calculated Bole Weights (1982 Sample)

Logs from the lower and upper sections were weighed by use of a load cell attached to a front-end loader. The bias and absolute error were computed to compare the calculated weight of the entire bole with the lifted weight. The procedure provides the means to investigate weight relationships for single logs, groups of logs, and entire boles.

The Development and Validation of Bole Prediction Equations (1982 Sample)

For both Douglas-fir and western hemlock, calculated bole weight (calculated volume multiplied by the measured green density is the dependent variable) was regressed against DBH and total tree height (the independent variables) to produce weight prediction models. The validation subsamples and additional offsite samples provided an indication of bias and absolute error for the calculated bole weight equations.

Results

Comparison of the Wood Disk Technique With the Xylodensimeter Technique

Table 2 shows the comparison of green densities derived from the wood disk techniques with green densities from the xylodensimeter. The estimates of green density were similar to those of the wood disk technique. The bias was negligible, and the absolute error was within 8 percent for all positions along the bole.

Table 2—Comparison of the wood disk technique with the xylodensimeter technique, 1981 sample logs

Position in tree and species	n 1/	Wood disk mean 2/	Bergstrom xylo. mean	Bias 3/	Relative bias 4/	Mean absolute difference 5/	Mean relative absolute difference 6/
		Pounds per cubic foot			Percent	Pounds per cubic foot	Percent
Butt log:							
Western hemlock	28	48.9	49.2	0.30	0.6	3.80	7.8
Douglas-fir	28	41.0	40.5	-.50	-1.2	3.06	7.5
Middle log:							
Western hemlock	28	49.5	48.9	-.60	-1.2	3.40	6.9
Douglas-fir	28	38.3	37.8	-.50	-1.3	2.51	6.6
Top log:							
Western hemlock	26	54.4	52.2	-2.20	-4.0	4.10	7.5
Douglas-fir	26	37.7	36.8	-.88	-2.3	2.35	6.2

1/ Number of paired samples.
2/ Volumetrically weighted green wood (sapwood + heartwood) densities.
3/ Bias is the mean of the differences between the disk and the xylodensimeter densities.
4/ Bias divided by wood disk mean multiplied by 100.
5/ Accuracy measure; the mean of the absolute differences between the disk and the xylodensimeter densities.
6/ Mean absolute difference divided by wood disk mean multiplied by 100.

Comparison of Lifted and Calculated Log Weights

Table 3 shows the comparison of calculated weights derived from an average density applied to an appropriate volume formula with lifted weights measured by a load cell. The bias was slightly negative for both species and all log positions. The absolute error was under 9 percent.

Table 3—Lifted weights and calculated weights, 1981 sample logs

Position in tree and species	n 1/	Mean lifted weight 2/	Mean calculated weight 3/	Bias 4/	Relative bias 5/	Mean absolute difference 6/	Mean relative absolute difference 7/
		Pounds			Percent	Pounds	Percent
Butt log:							
Western hemlock	28	4,020	3,986	-34	-0.8	343	8.5
Douglas-fir	28	6,292	6,095	-197	-3.1	489	7.8
2d log:							
Western hemlock	26	3,176	3,152	-24	-.8	267	8.4
Douglas-fir	27	4,501	4,446	-55	-1.2	255	5.7
3d log:							
Western hemlock	27	2,760	2,671	-89	-3.2	203	7.4
Douglas--fir	29	3,989	3,896	-93	-2.3	258	6.5
4th log:							
Western hemlock	20	2,637	2,573	-64	-2.4	210	8.0
Douglas-fir	25	3,835	3,743	-92	-2.4	282	7.4
Crown log:							
Western hemlock	11	1,881	1,849	-32	-1.7	118	6.3
Douglas-fir	23	3,339	3,223	-116	-3.5	219	6.8

1/ Number of paired samples.
2/ Measured with a load cell.
3/ Calculated with a xylodenismeter density and cubic volume formula.
4/ Bias is the mean of the differences between the lifted and the calculated weights.
5/ Bias divided by mean lifted weight multiplied by 100.
6/ Accuracy measure; the mean of the absolute differences between the lifted and the calculated weights.
7/ Mean absolute difference divided by mean lifted weight multiplied by 100.

Evaluation of Weight Prediction Equations

Table 4 summarizes the regression equations developed from the calculated weights. Total tree height was not a significant variable (F-test) for Douglas-fir. Equations for the calculated weights were used in predicting weights for whole boles of the 25 validation trees (table 5). By use of the same equations, bole weights for trees felled and bucked in 1981 from the three 5-acre plots were also predicted. With the exception of plot 3, the bias and absolute error of the prediction models remained within 20 percent. The large error in plot 3 was presumably due to the small size of the trees. Note the lower mean lifted weights for plot 3 compared with the other plots in table 5. This difference may be indirectly the result of the biological and physical factors of the site or a change in green density with time from 1981 to 1982 or both. Because of the lack of specific site information (for example, soil type, water-holding capacity), conclusions regarding influence of the site require further research.

Table 4—Calculated weight prediction equations, 1982 sample

Species	Prediction equations 1/	Sample size	R^2 2/	Mean square error 3/
Douglas-fir	W = exp(1.594+2.292(ln(DBH)) 4/	25	0.98	2442.2
Western hemlock	W = exp(1.794+2.315(ln(DBH))	25	.97	2415.7
Western hemlock	W= exp(-1.202+1.961(ln(DBH))+0.8374(ln(HT)))	25	.97	2511.6

1/ W = green weight of the bole in pounds; exp = 2.7183 to the power enclosed in parentheses; ln = natural logarithm; DBH = diameter at breast height in inches; HT = total height of the tree in feet.
2/ Coefficient of determination.
3/ For logarithmic functions, the mean square error of the residuals was calculated as the sum of the predicted minus the sum of the observed divided by the degrees of freedom, transformed to arithmetic units.
4/ The mean square error of residuals from transformed data divided by 2 was added to the intercept regression coefficient to correct for transformation bias (Baskerville 1972).

Table 5—Bias and accuracy evaluation of bole weight, 1982 samples

Population sample 1/ and species	n 2/	Lifted mean 3/	Calculated mean 4/	Bias 5/	Relative bias 6/	Mean absolute difference 7/	Mean relative absolute difference 8/
		----------Pounds----------			Percent	Pounds	Percent
Model trees, plot 4:							
Western hemlock	25	20,409	20,144	-265	-1.3	999	4.9
Douglas-fir	25	20,613	21,768	1,155	5.6	1,205	5.8
WITHIN POPULATION COMPARISON (TREES FROM THE SAME AREA)							
Validation trees, plot 4:							
Western hemlock	25	12,460	12,282	-178	-1.4	735	5.9
Douglas-fir	25	22,122	22,987	866	3.9	2,213	10.0
BETWEEN POPULATION COMPARISON (TREES FROM DIFFERENT AREAS)							
Plot 1:							
Western hemlock	14	14,974	14,548	-426	-2.8	1,729	11.5
Douglas-fir	13	26,818	30,251	3,433	12.8	5,379	20.1
Plot 2:							
Western hemlock	13	18,047	18,257	210	1.2	2,257	12.5
Douglas-fir	11	34,032	35,152	1,120	3.3	4,541	13.3
Plot 3:							
Western hemlock	3	2,340	2,817	477	20.4	495	21.1
Douglas-fir	5	7,123	8,554	1,431	20.1	1,617	22.7

1/ Observations used to build the regression equations. The equations were single predictor models (DBH) developed from the calculated weights. The western hemlock equation is weight (lb) = exp(1.794+2.315(ln(DBH)) and the Douglas-fir equation is weight (lb) = exp(1.594+2.292(ln(DBH)). Validation trees were used to test the accuracy and bias of the equations. Model trees and validation trees are from plot 4 and were sampled in the summer of 1982. Trees in plots 1 to 3 are from 3 different areas measured in the summer of 1981.
2/ Number of paired samples.
3/ Measured with a load cell.
4/ Calculated with a xylodensimeter.
5/ Bias is the mean of the differences between the lifted and the calculated weights.
6/ Bias divided by mean lifted weight multiplied by 100.
7/ Accuracy measure; the mean of the absolute differences between the lifted and the calculated weights.
8/ Mean absolute difference divided by mean lifted weight multiplied by 100.

Discussion

This study examines two phases of weight estimation for heavy-lift logging: green density measurement and model development. The first phase (1981) compares two techniques for measuring green density of wood, the Bergstrom xylodensimeter and the standard wood disk technique (table 2). The absolute error between the two techniques ranged from about 3 pounds per cubic foot in the butt logs to just over 2 pounds per cubic foot in the crown logs for old-growth Douglas-fir. The absolute error was higher for western hemlock; the butt logs were slightly under 4 pounds per cubic foot, the crown logs just over 4 pounds. The bias was negligible for both species and all bole positions.

Qualitative differences also exist between the two techniques. The primary advantage of the disk method is the ability to measure green density for individual structural components such as sapwood, heartwood, and bark. Dry density, green density, and moisture content may be considered separately for each sample disk. In addition, variation around the circumference of the bole is taken into account when the samples within a single disk are averaged. This may explain, in part, the observed absolute error between the two techniques. The disadvantages of the wood disk method include the high costs of sampling because of the time and labor needed for each measurement, the requirement of a laboratory with expensive scales and ovens, the destruction of the bole for each sample tree, and the inability to record density measurements directly in the field.

The attractive qualitative feature of the xylodensimeter technique is the ability to measure the green density of a log with the appropriate ratios of sapwood and heartwood contained in the sample. The method is not labor intensive and materials are inexpensive. Furthermore, numerous measurements can be taken relatively fast along the length of the bole. The readings are recorded directly in the field, and the technique is not as destructive to the bole as is the disk method. The principal disadvantage of this technique is the limited amount of information obtained per observation. The increment core is quite small in proportion to the size of the log; for example, an increment core with a diameter of 0.169 inch and a length of 6 inches has a volume equal to 0.000078 cubic foot. The sample core volume from the butt log in figure 6 is only equal to 0.00004 percent of the log volume. In addition, unless increment cores are taken around the bole at each height, the circumferential variation in density is not considered.

Estimates of log weights were determined from densities measured with the xylodensimeter (table 2). The results were better than expected when the sizes of the sample cores compared with those from the larger logs are considered. The bias indicators were low in all bole positions for both Douglas-fir and western hemlock (table 3).

In the second phase (1982) of the study, fewer trees (25) were selected but more measurements were taken. Equations were developed (table 4) from data from a small subsample and applied to other trees within the same population and from other populations. The results were good in view of the potential variation in density and volume of old-growth trees. Although the application of an equation developed in one area and applied to other areas may have caused an increase in absolute error for both species, the error in Douglas-fir was consistently higher than in western hemlock (table 5). The higher absolute error in Douglas-fir was believed to be caused by extensive heart rot in the butt section of the boles. Decay made it difficult to obtain a complete increment core.

The empirical bole model developed with calculated weights (1982) was evaluated to determine if weight prediction equations could be developed for a harvesting unit without lifting and weighing the boles. The results suggest that weights calculated with densities from the xylodensimeter may offer an alternative to lifting and weighing the boles. In areas of isolated or rugged terrain, where a preharvesting estimate of bole weight is needed, a forester could develop weight prediction equations from measurements of volume and green density.

How To Use the Xylodensimeter for Measuring Log and Bole Weights

Estimating log weight.—Figure 6 illustrates a method of determining individual log weights. The user must be able to identify the log's original position in the bole after bucking so that the appropriate volume equation can be applied. For example, a two-end conic rule is not an appropriate equation for the butt log. Logs in the field must also be physically separated so that diameters of log ends can be measured. A power-assisted increment boring tool that will increase the efficiency of the green density measurement is being investigated.

Predicting bole weight.—Figure 7 illustrates a method of measuring and developing prediction equations for total bole weight. We assumed that the variation in green density and the error associated with the calculation of volume in the lower portion of the bole would be higher than in the upper sections. This assumption was based on the fact that these logs can have atypical moisture conditions in the heartwood region because of pathological influence. Furthermore, in many aerial logging operations, the most critical estimate of weight is for the lower segment (butt log) because of the high value of the log. The data suggest that this assumption of high variation in the lower portion of the bole was indeed true; however, the upper section also demonstrated a high degree of variation in green density with height. There appears to be a change in green density in the upper bole of about 2 pounds per cubic foot with every 10 feet of height. This change was not necessarily in one direction. Green density actually decreased with height in two western hemlock trees, whereas it increased in the rest of the trees. In most applications, this variation may have little consequence because the bucked logs from the upper region of the bole are smaller and weigh considerably less than the lower logs. The concerned user may desire to take green density measurements at every diameter location in the upper section and avoid the interpolation of green density values.

In addition, the results suggested that the variation in green density within trees is equal to, or greater than, the variation between trees for specific locations. The user may wish to select fewer sample trees and to measure them more intensively. Bole weight prediction equations should be used with caution outside the specific area of development; for example, from a north aspect to a south aspect or from a ridgeline to a lower slope. Generally, we found that the absolute error increased for validation trees from different areas (table 5). Further research is needed on the effects of site on weight prediction equations.

Problems and Further Applications

Considerable variation in green density with height in old-growth Douglas-fir and western hemlock was discovered during the research on and development of the Bergstrom xylodensimeter. Therefore, measurements of green density taken at a specific location along the bole may or may not represent density at other locations. In addition, a technique to merge an iterative volume calculation with height is needed so that a user can compute the volume and weight of bole segments before logs are bucked. Research is being done to solve these problems.

The development and refinement of the weight prediction model currently underway will provide the user with a method of data collection and computation of prediction equations that is site-specific. The model will consider the weight of any bole segment, the total bole weight, and the bucking length options to achieve specific weight objectives for various size trees and lift capacities.

Conclusions

The Bergstrom xylodensimeter is useful for measuring wood densities, which can be applied to the estimation of log and bole weights. This new approach to estimating log weights promises to be useful for planning and conducting logging operations, especially with logging systems that have weight limits. The instrument is faster, more economical, and less destructive than the disk sampling technique.

Acknowledgment

This report presents results from a study conducted in cooperation with the Heli-Stat program, Timber Management, Region 6 (Pacific Northwest Region), USDA Forest Service. The authors acknowledge the assistance of Julie Kipp Bulgrin for supervising the field and laboratory work in collecting the data and for her assistance in data analysis.

Metric Conversions

English units	Multiplication factor	Metric units
inches	2.540	centimeters
feet	0.305	meters
cubic feet	0.028	cubic meters
pounds	0.454	kilograms
acres	0.405	hectares
pounds per cubic foot	16.019	kilograms per cubic meter
cubic feet per acre	0.070	cubic meters per hectare

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The performance of the Bergstrom xylodensimeter, designed to measure the green density of wood, was investigated and compared with a technique that derived green densities from wood disk samples. In addition, log and bole weights of old-growth Douglas-fir and western hemlock were calculated by various formulas and compared with lifted weights measured with a load cell attached to a front-end loader. The Bergstrom xylodensimeter accurately measured green wood density and is useful for estimating log weights.

Keywords: Log measurements, boles, wood density, cubic volume measure, measuring equipment, old-growth stands.

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LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR

REPORT NO. 7

PRELIMINARY RESULTS, STAMPEDE CREEK, AND SOME COMPARISONS WITH IRON CREEK AND HOSKINS

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture
Forest Service
Portland, Oregon

Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock

Thinning	Treatment							
	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Abstract for Report No. 1

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock which is established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and Vancouver Island, Canada. Site quality of these areas varies from I through IV.

Climatic and soil characteristics for each area and data for the stand after the conditioning thinning are described briefly.

KEYWORDS: Thinnings, stand growth, Douglas-fir, *Pseudotsuga menziesii.*

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR

Report No. 7—Preliminary Results, Stampede Creek, and Some Comparisons With Iron Creek and Hoskins

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USDA Forest Service Research Paper PNW-323
Pacific Northwest Forest and Range Experiment Station
Forest Service Portland, Oregon
U.S. Department of Agriculture 1984

Other LOGS (levels-of-growing stock) reports:

WILLIAMSON, RICHARD L.; STAEBLER, GEORGE R. A cooperative level-of-growing-stock study in Douglas-fir. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1965.** 12 p.
Describes purpose and scope of a cooperative study which is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands are also summarized.

WILLIAMSON, RICHARD L.; STAEBLER, GEORGE R. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 1—Description of study and existing study areas. Res. Pap. PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1971.** 12 p.
Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

BELL, JOHN F.; BERG, ALAN B. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 2—The Hoskins study, 1963-1970. Res. Pap. PNW-130. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1972.** 19 p.
A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

DIGGLE, P. K. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (Report No. 3, Cooperative L.O.G.S. study series). Inf. Rep. BC-X-66. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre; **1972.** 46 p.

WILLIAMSON, RICHARD L. Level-of-growing-stock cooperative study in Douglas-fir: Report No. 4—Rocky Brook, Stampede Creek, and Iron Creek. Res. Pap. PNW—210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1976.** 39 p.
The USDA Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels of growing stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

BERG, ALAN B.; BELL, JOHN F. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 5—The Hoskins Study, 1963-1975. Res. Pap. PNW-257. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1979.** 29 p.
The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

ARNOTT, J. T.; BEDDOWS, D. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 6—Sayward Forest, Shawnigan Lake. Inf. Rep. BC-X-223 Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre; **1981.** 54 p.

Data are presented for the first 8 and 6 years at Sayward Forest and Shawnigan Lake, respectively. The effects of the calibration thinnings are described for these two installations on Vancouver Island, British Columbia. Results of the first treatment thinning at Sayward Forest for a 4-year response period are also included.

Reference Abstract

WILLIAMSON, RICHARD L.; CURTIS, ROBERT O. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 7—Preliminary results, Stampede Creek, and some comparisons with Iron Creek and Hoskins. Res. Pap. PNW-323. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 42 p.

Results of the Stampede Creek LOGS study in southwest Oregon are summarized and results are compared with two more-advanced LOGS studies and, in general, are similar. To age 43, thinning in this low site III Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) stand resulted in some reduction in volume growth and moderate gains in diameter growth. Growth was strongly related to level of growing stock. Desirable density levels are recommended for young Douglas-fir stands.

KEYWORDS: Growing stock (-increment/yield, increment -)growing stock management, stand density, thinnings, Douglas-fir, *Pseudotsuga menziesii*, southwest Oregon, Oregon (southwest), series—Douglas-fir LOGS.

Research Summary

Results of the Stampede Creek LOGS study in southwest Oregon are summarized through the first treatment period. Results are compared with those from two more-advanced LOGS studies and, in general, are similar. To age 43, thinning in this low site III Douglas-fir *(Pseudotsuga menziesii)* (Mirb.) Franco) stand resulted in some reduction in volume growth and moderate gains in diameter growth. Gains from thinning would be minor if this stand were harvested now, but the comparisons indicate a much more favorable evaluation of thinning when rotations are longer or stands are on higher sites. Growth was strongly related to growing stock level, and there is little indication of any plateau of constant growth over a range of stocking in young stands. Recommendations are made for desirable density levels in young Douglas-fir stands.

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Introduction

The Stampede Creek levels-of-growing-stock (LOGS) study is one of nine thinning studies established in young, even-aged Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) stands according to a common work plan (Williamson and Staebler 1971) (see appendix 1 in this report). These studies are a regional cooperative effort involving Weyerhaeuser Company, Oregon State University, Washington Department of Natural Resources, Canadian Forestry Service, and the USDA Forest Service. The objective is to compare tree and stand development under eight thinning regimes, begun before the onset of severe competition between trees. When the study was established, trees in all areas generally had live branches down to breast height, but other stand characteristics varied considerably among areas.

The Stampede Creek stand is located on the Tiller Ranger District, Umpqua National Forest, near Tiller in southwest Oregon (fig. 1). It is of natural origin after wildfire. When the study was established in 1968, the stand was older (33 years) and taller than other LOGS stands were at the time of study establishment. The ages of dominant and codominant trees varied from 29 to 36 years. Elevation is 2,700 feet. Soils are heavy loam over heavy clay loam and clay derived from well-weathered volcanic tuffs and breccias. Average (1972-78) growing season (May-September) temperature and precipitation are 54.9 °F and 7.71 inches. Based on the 1978 measurement, estimated average site index (based on crop tree heights) is about 100 in King's (1966) system (50 years at breast height), and 120 according to McArdle and others (1961) at 100 years total age.

The Stampede Creek study, like the other LOGS studies, is a completely randomized experiment comparing eight thinning regimes, with three replications each, plus control. An initial "calibration" thinning at age 33 reduced all treated plots to a common basal area level (table 1). Subsequent thinnings retain varying percentages of gross periodic increment observed on the untreated control plots (inside front cover) and are expected to produce the basal area trends shown schematically in figure 2. The thinning interval is the time required for crop trees to grow 10 feet in height (averaged over all treatments). The principal features of the general LOGS plan are reproduced in appendix 1, and they are more fully described by Williamson and Staebler (1971).

The Stampede Creek study has completed only the calibration (ages 33-38) and first treatment (ages 38-43) growth periods. This report presents some interim results of the Stampede Creek study as of the end of the first treatment period and updates a previous report (Williamson 1976). Early results from this and similar studies can provide some information on desirable levels of growing stock for intensively managed young stands. Early results from the Stampede Creek study are of particular interest in connection with the FIR program,[1] because this is the only LOGS study located in southwest Oregon.

[1]Funding for preparation of LOGS Report 7 was provided by the FIR (Forestry Intensified Research) program for southwestern Oregon, administered by Oregon State University and the Pacific Northwest Forest and Range Experiment Station.

Figure 1.—Triangles indicate locations of the nine levels-of-growing-stock studies in coastal Douglas-fir.

Table 1—Stand values after the calibration thinning for the Stampede Creek, Iron Creek, and Hoskins LOGS studies

Study area and year established	Estimated site index at index age (years): 50, 1/ breast height	100, 2/ total	Age: Breast height	Age: Total	Average height of crop trees	Quadratic mean d.b.h.: Control	Quadratic mean d.b.h.: Thinned	Number of trees, all species: Control	Number of trees, all species: Thinned	Basal area: Control	Basal area: Thinned
	Feet		Years		Feet	Inches		Per acre		Square feet per acre	
Stampede Creek, 1968	100	120	25	33	56	4.7	6.6	995	290	118.5	68.1
Iron Creek, 1966	127	150	12	19	36	3.7	5.0	1,125	335	82.0	47.4
Hoskins, 1963	130	160	13	20	36	3.8	5.2	1,727	345	113.8	49.8

1/King (1966).
2/McArdle and others (1961).

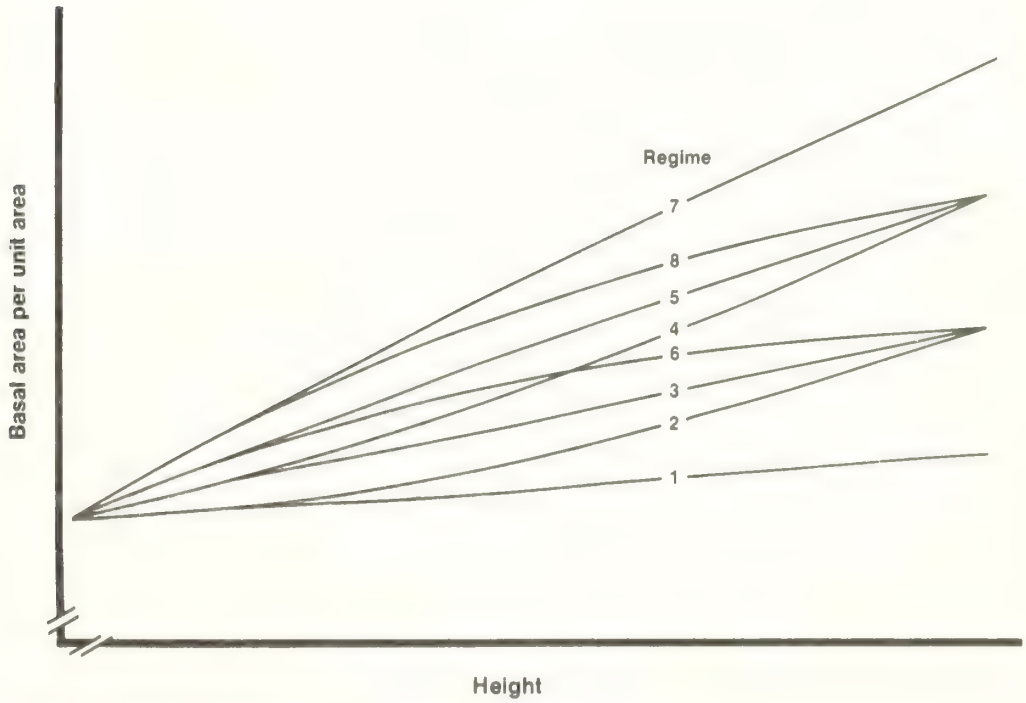


Figure 2.—Levels-of-growing-stock study in Douglas-fir: idealized trends of basal area for the eight thinning regimes.

This report also makes some comparisons with results from two other LOGS studies, Iron Creek (Williamson 1976) and Hoskins (Berg and Bell 1979). The Iron Creek and Hoskins studies are on higher sites and differ in some other respects (table 1). Because Iron Creek and Hoskins are now further advanced in the planned treatment sequence, comparisons may provide some indications of consistency of results at different locations and of the probable applicability of results from other LOGS studies to stands of the Pacific Douglas-fir type (Williamson 1980) in southwest Oregon.

Objectives

The objectives of this report are to:

1. Present revised data summaries showing development of the Stampede Creek LOGS stands through age 43 (end of the first treatment period). These tables incorporate the most recent measurement and replace the tables published by Williamson in 1976.

2. Compare results from the Stampede Creek LOGS study with the Iron Creek and Hoskins studies for: (a) relationship of growth to growing stock, (b) growth of crop trees versus growth of all trees, (c) growth by treatment groups, and (d) effects of treatments on tree size and merchantable volumes.

3. Compare consistency of results at Stampede Creek, Iron Creek, and Hoskins LOGS studies for (a) initial stand densities, (b) growth of thinned stands relative to growth of controls, (c) relationship of growth to growing stock for all available periods and for the period at each area when initial heights of crop trees averaged about 65 feet, and (d) gross yields relative to stand age and to average height of crop trees.

4. Examine the possibility that results at Iron Creek and Hoskins are indicative of probable future development of the Stampede Creek study.

Data Summarization

Volume and increment statistics discussed in this report were obtained by the following procedures:

1. Diameters (to the nearest 0.1 inch) at breast height were measured on all trees 1.6 inches in d.b.h. (diameter at breast height) and larger on each plot.

2. Total height (to the nearest foot) was measured on a sample of at least 15 randomly chosen trees per plot, distributed throughout the diameter range, with two-thirds of the sample trees larger than the stand quadratic mean diameter.

3. Total volume, inside bark, was calculated for each sample tree by the Bruce and DeMars (1974) volume equation.

4. Total cubic volume of every tree on each plot was calculated, using a regression logarithm of volume on logarithm of diameter at breast height fit to the sample tree measurements for that plot and measurement date. Plot volume was then calculated as the summation of tree volumes.

5. Periodic gross growth in total cubic volume was calculated as the difference between live volumes at start and end of the growth period, plus mortality and ingrowth.

Data compilations for all three study areas were done with a common set of computer programs. Complete summaries are given for all available periods for Stampede Creek (tables 5 to 10 in appendix 2 and 16 to 33 in appendix 3). Data for the Hoskins study are from Berg and Bell (1979), plus unpublished data for the 1975-79 period provided by John Bell of Oregon State University. Pertinent values for Iron Creek are given in tables 11 to 15 (appendix 2), including previously unpublished data for the 1973-77 and 1977-80 periods.

Results—Stampede Creek

Calibration Period

All trees.—Prethinning numbers of trees and basal areas were about 83 percent of normal for the stand diameter (table 25 in McArdle and others 1961). This suggests relatively low competition and incomplete site utilization at younger ages and is consistent with the observation that live crowns extended nearly to breast height at the time of study establishment.

Gross volume growth of thinned plots was 80 percent of that of control plots (table 2) even though the mean volume in cubic feet was only 66 percent of the volume of the controls. Average growth percent (based on mean growing stock for the period) of thinned plots was 10.0, compared with 8.3 for controls.[2/] Growth per unit of growing stock volume on the thinned plots was about 20 percent (10.0/8.3) higher than on the control plots.

Table 2—Stampede Creek: periodic annual gross volume growth, growing stock, growth percent, and initial volume per tree for crop trees, noncrop trees, and all trees, ages 33-38, calibration period

Component and treatment	Gross growth per year	Mean growing stock	Growth percent 1/	Initial volume per tree	Ratio, thinned:control		
					Gross growth	Growing stock	Growth percent
	- - Cubic feet per acre - -		Percent	Cubic feet			
Crop trees:					1.12	.99	1.13
Thinned	104	1,011	10.28	9.40			
Control	93	1,022	9.10	9.88			
Noncrop trees:					.60	.48	1.24
Thinned	92	937	9.77	3.45			
Control	153	1,934	7.91	1.71			
All trees:					.80	.66	1.21
Thinned	196	1,948	10.04	5.08			
Control	246	2,956	8.32	2.36			

1/Calculated as percentage of mean growing stock for the period.

Crop trees.—Crop trees had been chosen on the basis of spacing, dominance, and vigor, as trees expected to be retained in subsequent thinnings. Crop trees in thinned plots grew 12 percent more than those in control plots, though later discussion suggests that some of this improvement was due to a slight edge in beginning volume for control trees (table 2). Average growth percent of crop trees for thinned plots was 10.3 compared with 9.1 for controls (table 2). This suggests a 13-percent (10.3/9.1) improvement in growth per unit of growing stock volume because of thinning.

First Treatment Period

All trees.—Average gross growth on the thinned plots during this period was 80 percent of gross growth on the control plots, whereas growth per unit of growing stock volume was about 28 percent higher on the thinned plots than on the controls (table 3).

[2]Growth percents used in this report were calculated as:

$$\frac{100(\text{periodic annual increment in } X)}{(X_1 + X_2)/2}$$

where: X_1 and X_2 are values of the variable at start and end of the growth period. This expresses current rate of change in X in relation to mean value of X for the period, rather than the initial value of X used in previous LOGS reports. The change in method of computation was made to facilitate comparisons among different installations.

Table 3—Stampede Creek: periodic annual gross volume growth, growing stock, growth percent, and initial volume per tree for crop trees, noncrop trees, and all trees, ages 33-38, by treatment group, 1st treatment period

Component and treatment	Gross growth per year	Mean growing stock	Growth percent 1/	Initial volume per tree	Ratio, thinned:control	
					Gross growth	Growth percent
	Cubic feet per acre		Percent	Cubic feet		
Crop trees:					1.14	1.09
1 and 2	140	1,612	8.7	15.8		
3 and 4	132	1,534	8.6	15.0		
5 and 6	136	1,612	8.4	15.9		
7 and 8	135	1,667	8.0	16.9		
Control	119	1,551	7.7	15.7		
Noncrop trees:					.56	1.42
1 and 2	68	755	9.0	5.3		
3 and 4	94	1,044	9.0	6.7		
5 and 6	103	1,117	9.2	4.9		
7 and 8	106	1,331	8.0	6.4		
Control	166	2,680	6.2	2.5		
All trees:					.80	1.28
1 and 2	208	2,367	8.8	9.7		
3 and 4	226	2,578	8.8	10.0		
5 and 6	238	2,729	8.7	8.4		
7 and 8	241	3,018	8.0	9.8		
Control	285	4,231	6.7	3.5		

1/Calculated as percentage of mean growing stock for the period.

The treatments combined in table 3 were identical for the first treatment period (see treatment schedule on inside front cover); during this period, there are effectively four thinning treatments, plus control. Differences in gross growth among these four treatment groups for the first treatment period were (barely) significant at the 0.10 level; treatment means of gross growth increased from treatments 1 and 2 through 7 and 8.

Gross growth of control plots during this period (table 3) was roughly equivalent to normal yield table estimates for midsite III (Curtis 1967, Curtis and others 1982, Staebler 1955).

When gross volume growth per year is plotted over periodic average growing stock (fig. 3), a positive slope is evident. If only the thinned plots are considered, the relationship approximates a straight line through the origin.

In figure 4 we have chosen to fit the data, including the controls, with the equation $Y = bX - cX^2$ because:

1. This meets the logical requirements that zero stocking should produce zero growth and that growth cannot increase indefinitely as stocking increases.

2. This is the equation of best fit (minimum standard error of estimate) when the control plots are included, and the curves with and without the control plots are almost the same.

3. This is the curve form found best in concurrent work with the Iron Creek and Hoskins data.

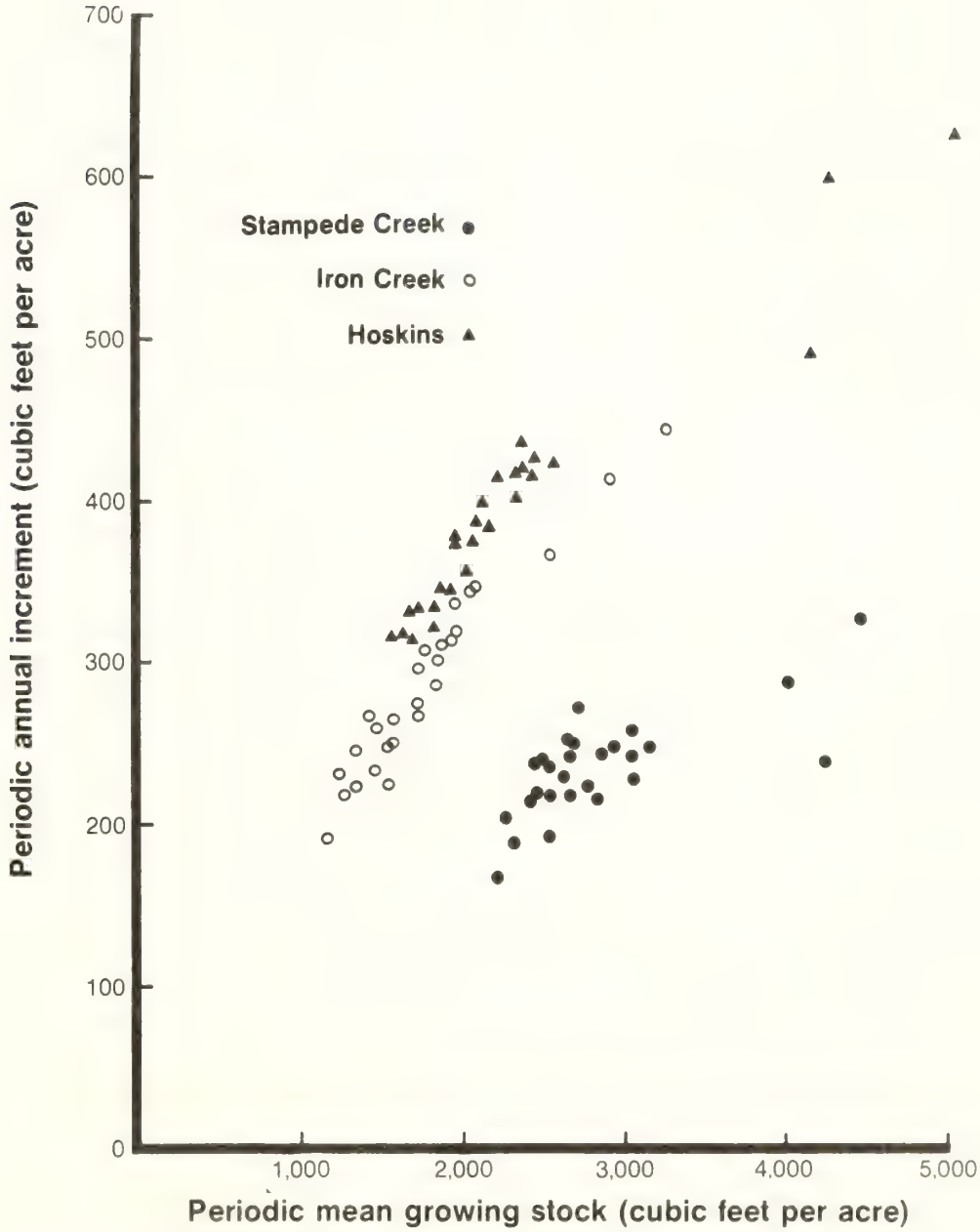


Figure 3.—Stampede Creek, Iron Creek, and Hoskins: periodic annual gross volume increment (trees 1.6 inches in d.b.h. and larger) in relation to volume of growing stock, first treatment period

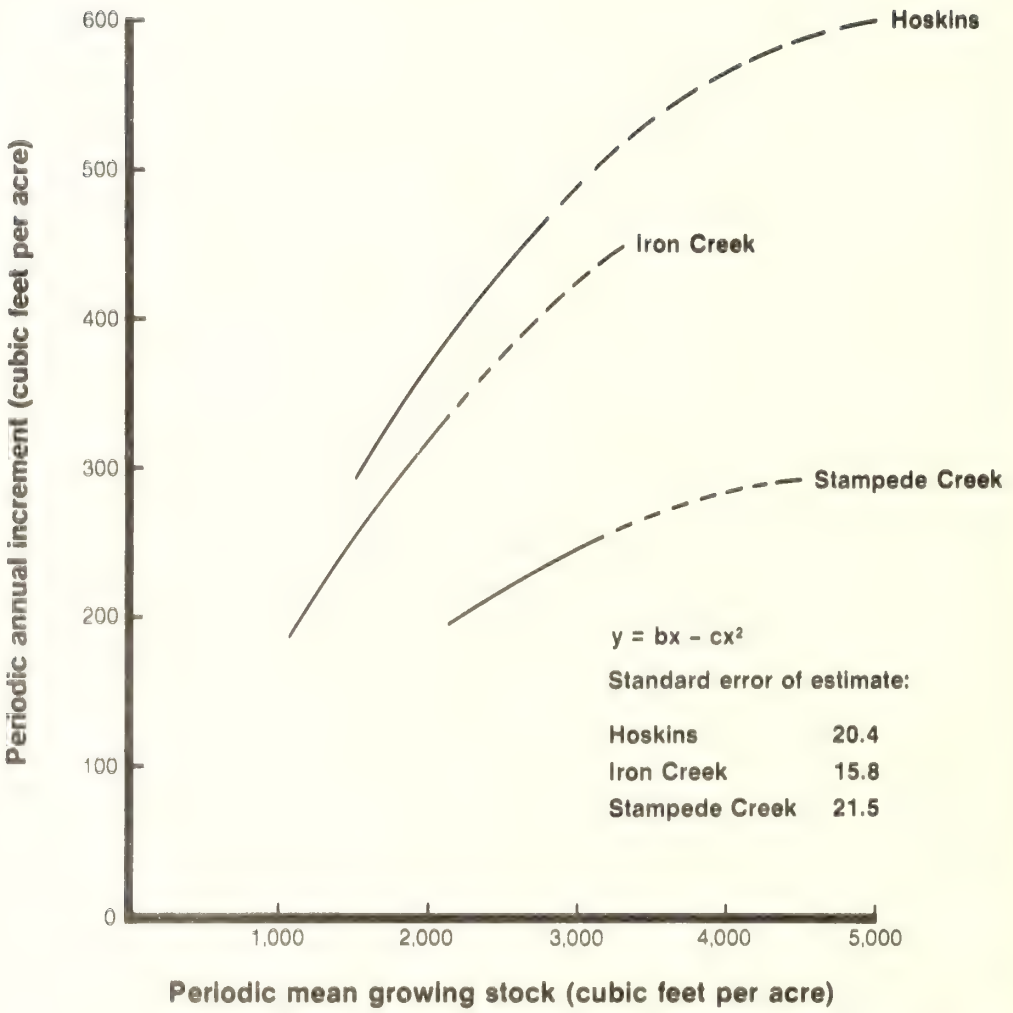


Figure 4.—Stampede Creek, Iron Creek, and Hoskins: regressions expressing periodic annual gross volume increment (trees 1.6 inches in d.b.h. and larger) as a function of volume of growing stock, first treatment period. Solid portions of curves represent range of thinned plot data; dashed portions include range of control plots.

Variability about the regression was greater and the curve was less clearly defined than for the comparable period at Iron Creek and Hoskins (fig. 3). This could be related to the initially greater height and less homogeneous stand conditions at Stampede Creek than at the other two areas.

Crop trees.—Gross volume growth percent for crop trees in treatments 1 and 2 was 8.7 percent compared with 7.7 percent for controls. Inspection of growth percents by treatment groups suggests a trend of decreasing growth percents with increase in growing stock, although differences were not statistically significant (table 3).

Growth percents for crop trees in all thinning treatments (except 7 and 8) were slightly less than those for noncrop trees, probably reflecting the greater average size of crop trees. Since tree size affects growth percent, a more meaningful comparison is that of crop trees and all trees at the times their average dimensions were similar. Average heights and diameters were comparable for crop trees at the start of the calibration period and for all trees at the start of the first treatment period. For comparable tree size, growth percents of crop trees exceeded those of all trees. This suggests that the smaller trees (in these thinned stands, codominants) grew less efficiently than the larger trees.

A similar result has been obtained in an older stand (Williamson 1982). Both growth efficiency and stand security considerations indicate that larger trees should be favored.

Cubic volume yields to age 42.—Tables 16 to 33 in appendix 3 illustrate the yields obtained at Stampede Creek by tree diameter at breast height, both separately and cumulatively, from largest diameter to smallest for each of the eight thinning treatments and the unthinned control.

Figure 5 shows cumulative cubic volume production in trees larger than 7.6, 9.6, and 11.6 inches for eight thinning treatments and the control. At age 43, after 10 years of thinning, average cumulative yield of the thinned plots in trees 7.6 inches and larger is 86 percent of that of the control plots. Cumulative yield of thinned plots in trees 9.6 inches and larger is about the same as that of the controls, whereas yield in trees 11.6 inches and larger is 140 percent of that of the controls. At age 43, average diameters range from 6.1 inches for the controls to 10.4 inches for treatment 1.

This stand was of natural origin, somewhat uneven aged, with considerable crown differentiation. To age 43, thinning has produced no gains in usable fiber production, if all trees 7.6 inches and larger are assumed to be merchantable. All thinning treatments exceed the controls in volumes of trees over 11.6 inches, however, and the effects of thinning in increasing tree size and value should become more evident with advancing age.

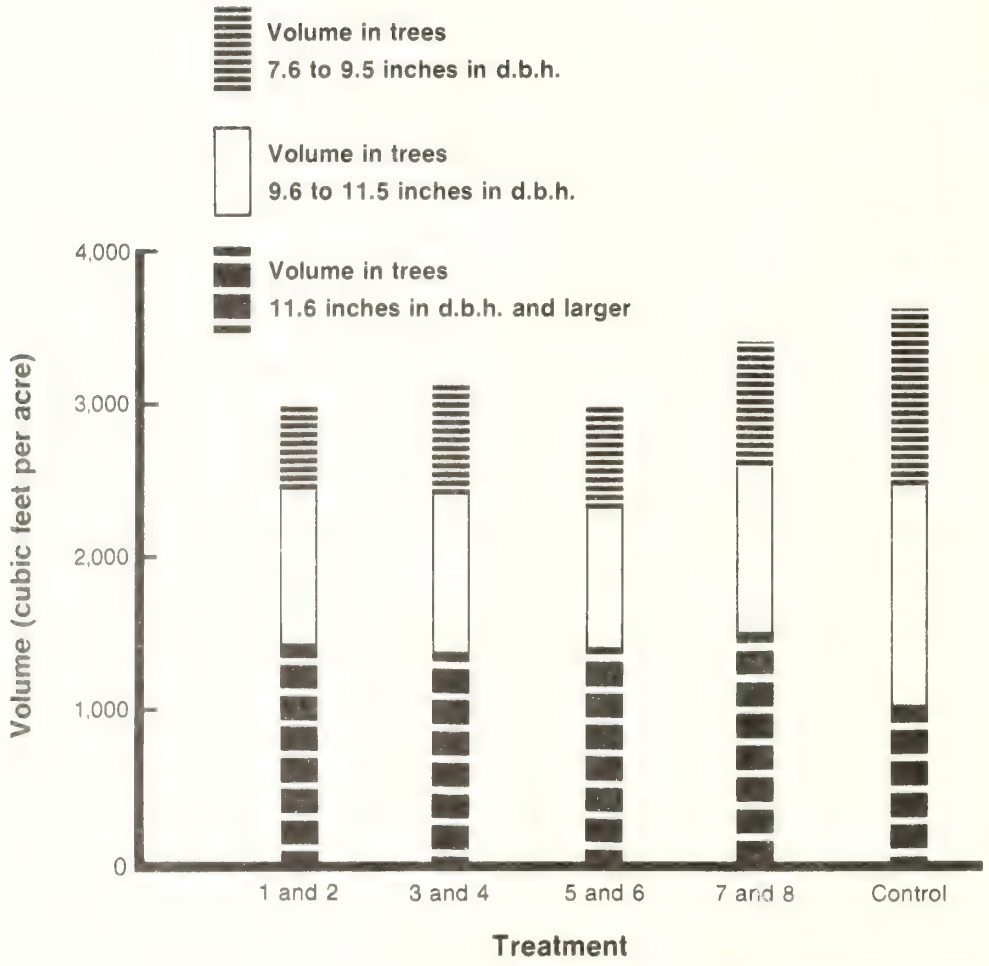


Figure 5.—Stampede Creek: cumulative volume production for trees 11.6 inches in d.b.h. and larger and for trees 9.6 to 11.5 and 7.6 to 9.5 inches in d.b.h. at end of first treatment period (age 43). Volumes are for live stand at age 43, plus trees cut in thinning (calibration cut excluded).

Results—Comparisons With Iron Creek and Hoskins

Initial Stand Conditions

The Iron Creek and Hoskins study areas were initially similar in stand characteristics, except for a much greater number of trees at Hoskins. Although Iron Creek and Hoskins controls started with the same average crop tree height and a considerable difference in number of trees, initial average diameters were almost identical; evidently, initial competition was low. The Stampede Creek stand was older and considerably taller at the time of establishment than were the Iron Creek and Hoskins stands (table 1). Iron Creek was a plantation with considerable natural fill-in. Hoskins was an unusually uniform natural stand. Stampede Creek was a natural stand with considerably more variation in tree ages and sizes.

A relative density scale useful in comparisons is provided by a measure (Curtis 1982) defined as:

$$RD = (\text{basal area})/(Dg)^{1/2};$$

where: Dg is quadratic mean diameter, and the units are square feet per acre for basal area and inches for diameter. This measure is similar to Reineke's (1933) Stand Density Index but more convenient to use. Dividing RD values by 65 gives a close approximation to normality ratio according to table 25 in McArdle and others (1961).

Values of RD for the control plots at the time of the calibration thinning were:

Stampede Creek	55
Iron Creek	43
Hoskins	71

The common study plan for the regional cooperative LOGS studies assumed that the spacing equation used to guide the calibration thinning would provide equal levels of competition among installations that differ in initial average diameter and would thereby facilitate comparisons between areas. Average RD values for the thinned plots at the end of the calibration period were 34, 32, and 33 at ages 38, 23, and 23 for Stampede Creek, Iron Creek, and Hoskins. This goal was accomplished.

Subsequent to the calibration period, the Hoskins control plots have developed and maintained extremely high densities. At the end of the first treatment period, RD values for these plots were 74, 74, and 95 for Stampede Creek, Iron Creek, and Hoskins. Increases since the calibration thinning were consistent with site, age, and initial stocking. The Hoskins control had 37 percent more basal area and 54 percent more volume than the Iron Creek control. Since then, Hoskins has stabilized at RD's just below 100. The Iron Creek control was at RD 92 at age 33 and appears to be approaching the RD of the Hoskins control as initial differences in density are reduced through greater natural mortality at Hoskins.

Growth Relative to Control Plot Growth

Calibration period.—For the calibration period, the ratios of gross volume growth of thinned plots to growth of control plots follow a logical order for the three studies (table 4). Stampede Creek has the largest ratio (0.80), perhaps because of greater average height and slightly higher relative density. Hoskins is lowest (0.61), probably because the much greater initial density resulted in greater growth of the control and in a heavier calibration thinning.

First treatment period.—A similar comparison (fig. 6) for the first treatment period shows that differences among thinning treatments in gross volume increment as percents of control plot growth were much more pronounced for Iron Creek and Hoskins (which behaved similarly) than for Stampede Creek. The reason for this difference in response is not clear; it may be associated with the later start of thinning (both in years and in attained stand height) at Stampede Creek.

Table 4—Periodic annual net growth in quadratic mean diameter, and gross growth in basal area and total cubic volume during the calibration period—Stampede Creek, Iron Creek, and Hoskins studies

Study and treatment	Total age	Net growth in quadratic mean diameter	Gross growth in basal area	Gross growth in total volume	Ratio, thinned:control	
					Gross volume growth	Net diameter growth
	Years	Inch	Square feet per acre	Cubic feet per acre		
Stampede Creek:	33-38				0.80	2.89
Control		0.09	7.0	246		
Thinned		.26	5.8	196		
Iron Creek:	19-23				.72	2.16
Control		.19	12.1	306		
Thinned		.41	9.0	219		
Hoskins:	20-23				.61	2.62
Control		.21	16.2	469		
Thinned		.55	12.3	285		

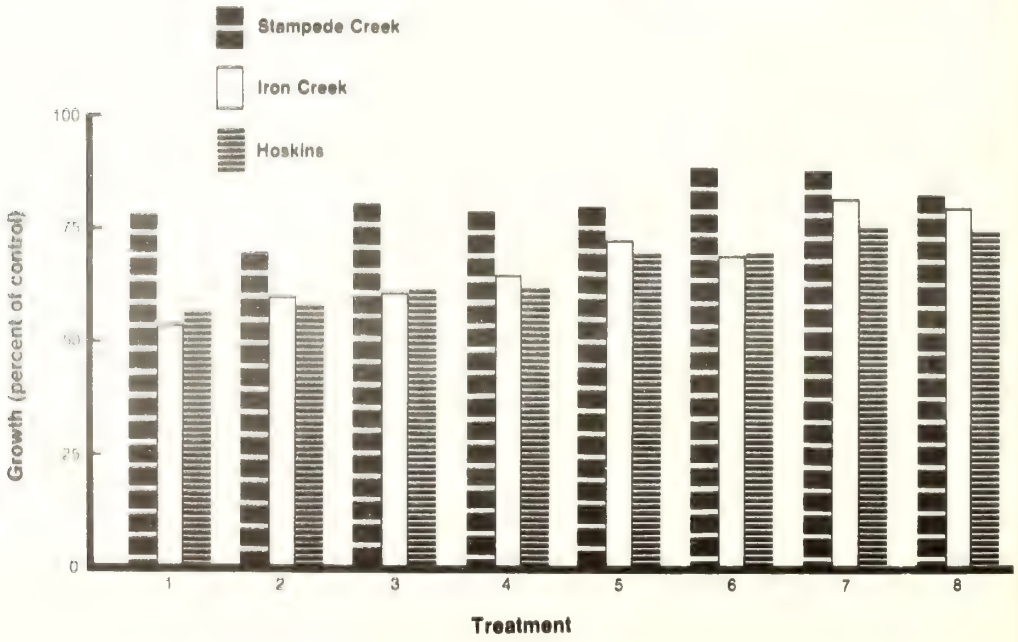


Figure 6.—Stampede Creek, Iron Creek, and Hoskins gross cubic volume growth (trees 1.6 inches in d.b.h. and larger) by treatments, expressed as percentages of growth of control, first treatment period.

Growth:Growing Stock Relationships

Curves of periodic annual increment in gross volume over mean volume by periods (fig. 4) indicate much lower gross growth rates for given levels of growing stock at Stampede Creek than at the other two areas. Conversely, results for Iron Creek and Hoskins are much closer (figs. 4, 7, and 8). The lesser growth:growing stock ratios at Stampede Creek reflect its greater age and lower site index.

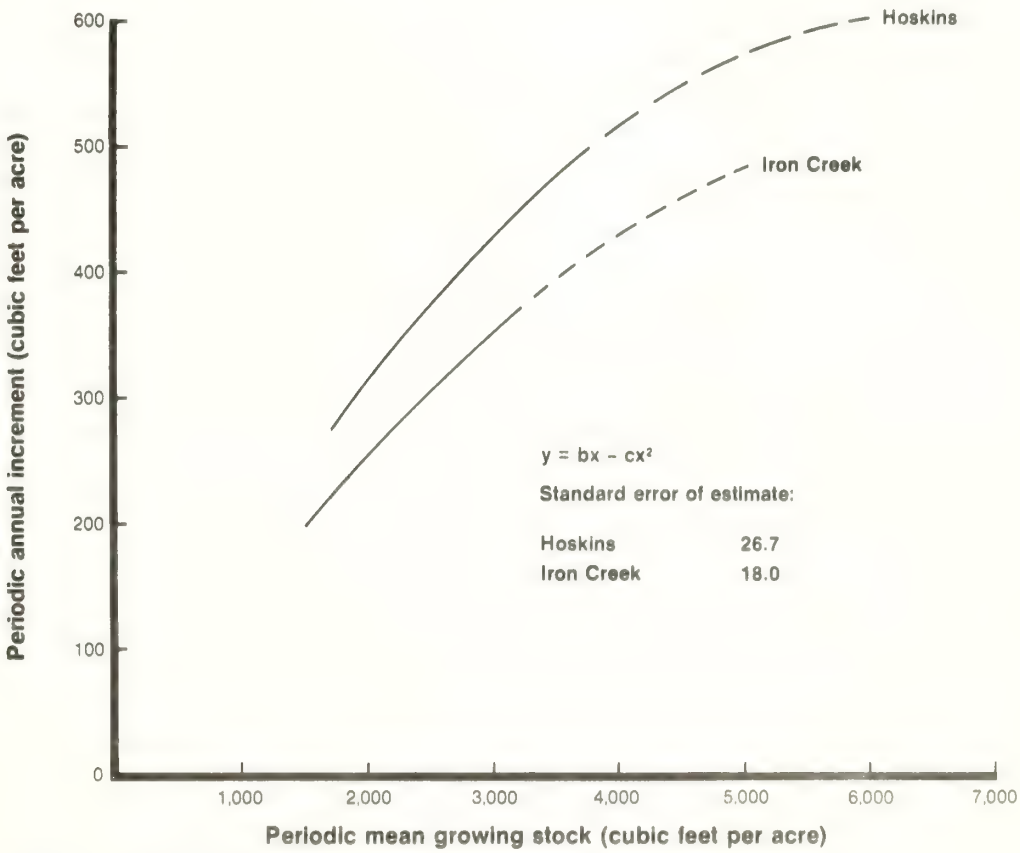
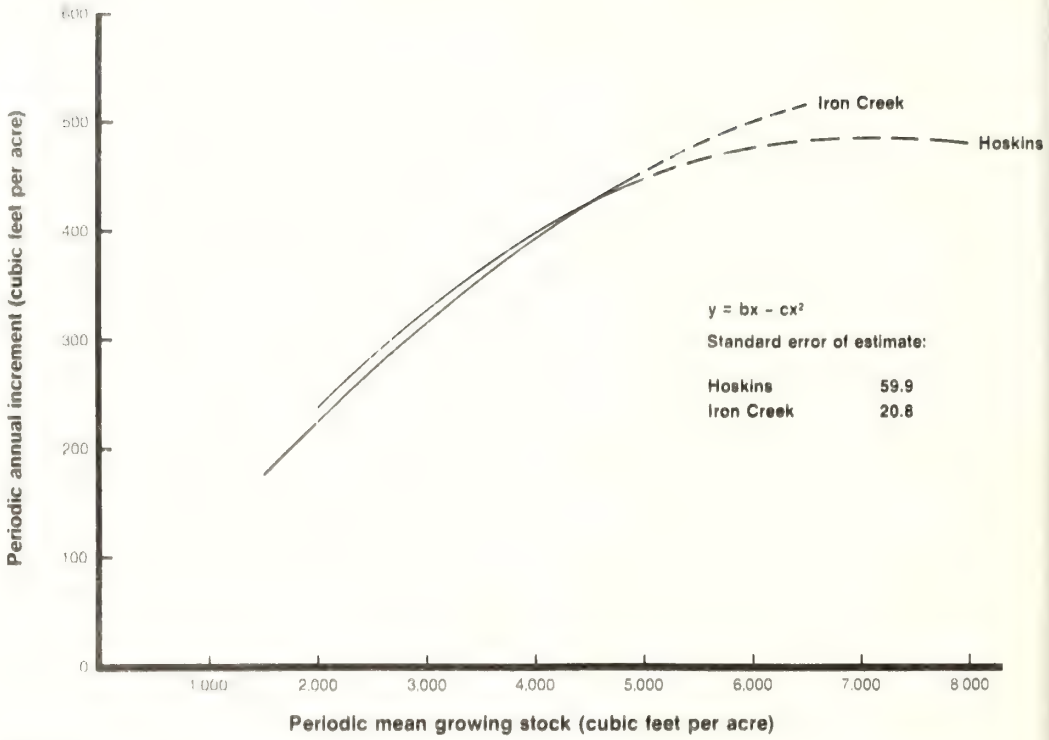


Figure 7.—Iron Creek and Hoskins: regressions expressing periodic annual gross volume increment (trees 1.6 inches in d.b.h. and larger) as a function of volume of growing stock, second treatment period. Solid portions of curves represent range of thinned plot data; dashed portions include range of control plots.

...ron Creek and ...regressions express-...g per... annual gross volume increment (trees 1.6 inches ... d.b.h. and larger) as ... function of volume of growing stock, ... treatment period. Solid portions of curves represent range of thinned plot data; dashed portions include range ... control plots.



Gross Yields Relative to Stand Age

Relationships of gross yields to stand age (fig. 9) correspond to those expected according to age, site index, and initial stocking. Iron Creek is not illustrated because trends there were similar to those at Hoskins. Stampede Creek has substantially lower site index than the other two areas; thus, slopes of the yield curves are less. Though initial volume at Stampede Creek was about the same as that at Hoskins, Stampede Creek was 13 years older when the study was established.

Though well into the planned thinning regimes, with 40 to 50 feet of height growth since the calibration thinning, both Iron Creek and Hoskins are still in a period of growth acceleration for the control and most treatments, as shown by the upward curvature of these yield curves (fig. 9).

Gross Yields Relative to Stand Height

Cumulative yields by treatments in gross cubic feet per acre for Hoskins and Stampede Creek are shown plotted over average height of crop trees in figure 10. (Curves for Iron Creek were similar to those for Hoskins and are not shown.) Mortality has been negligible at these two areas, except on the Hoskins control plots where about 12 percent of gross production was lost to mortality. The wide spread in cumulative yields among the Hoskins thinning treatments corresponds to the relationship of growth to growing stock shown in figures 6 to 8.

Figure 9.—Hoskins and Stampede Creek: cumulative gross yield (trees 1.6 inches in d.b.h. and larger, calibration cut excluded) in relation to stand age, for controls and for thinning treatments 1, 3, 5, and 7. Net yield is shown for Hoskins control only.

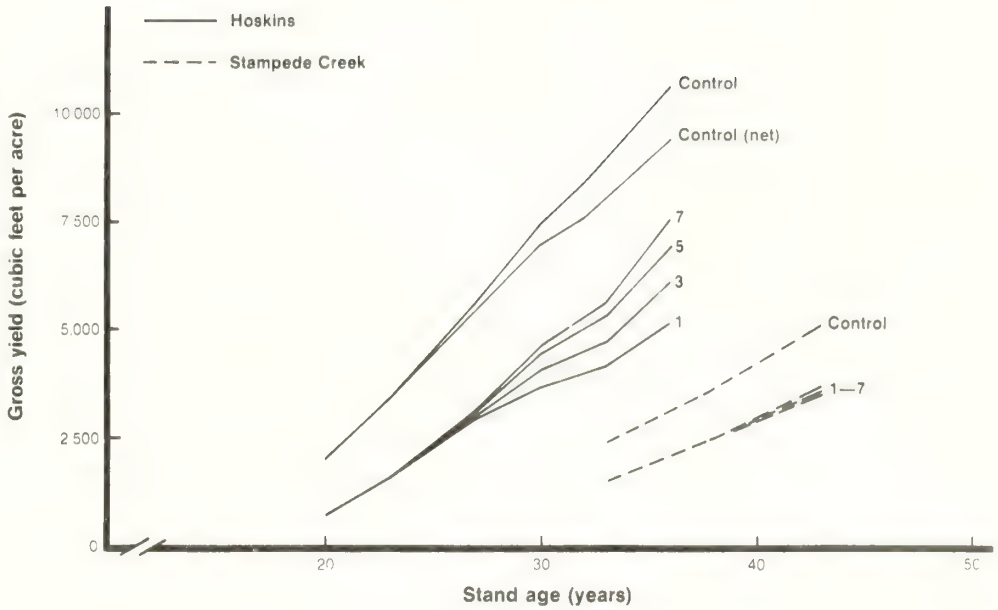
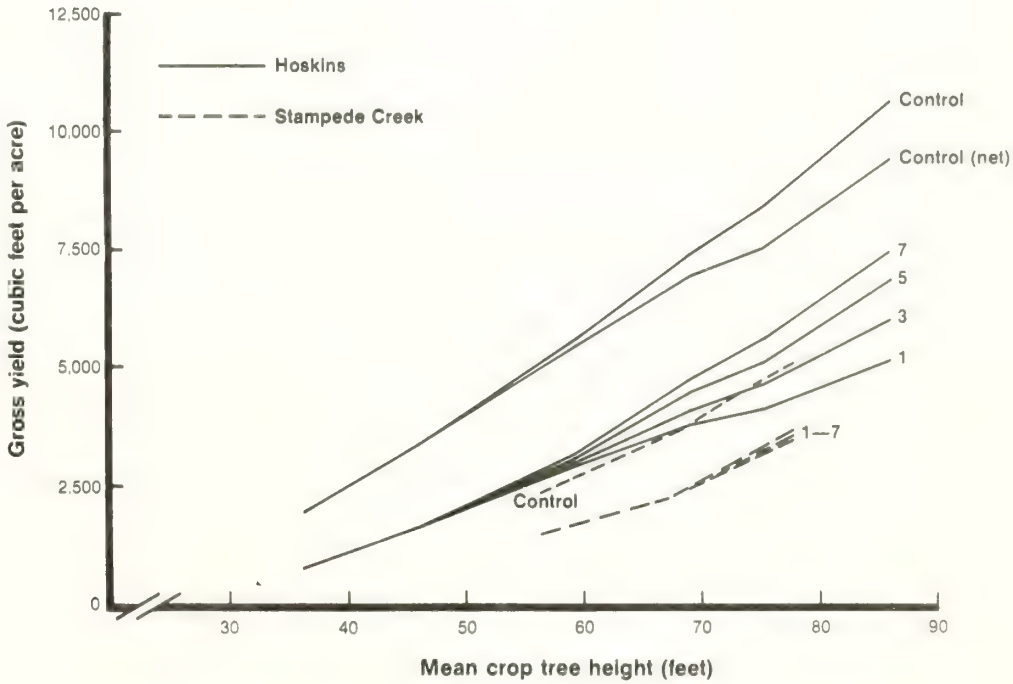


Figure 10.—Hoskins and Stampede Creek: cumulative gross yield (trees 1.6 inches in d.b.h. and larger, calibration cut excluded) in relation to mean height of crop trees, for controls and for thinning treatments 1, 3, 5, and 7. Net yield is shown for Hoskins control only.



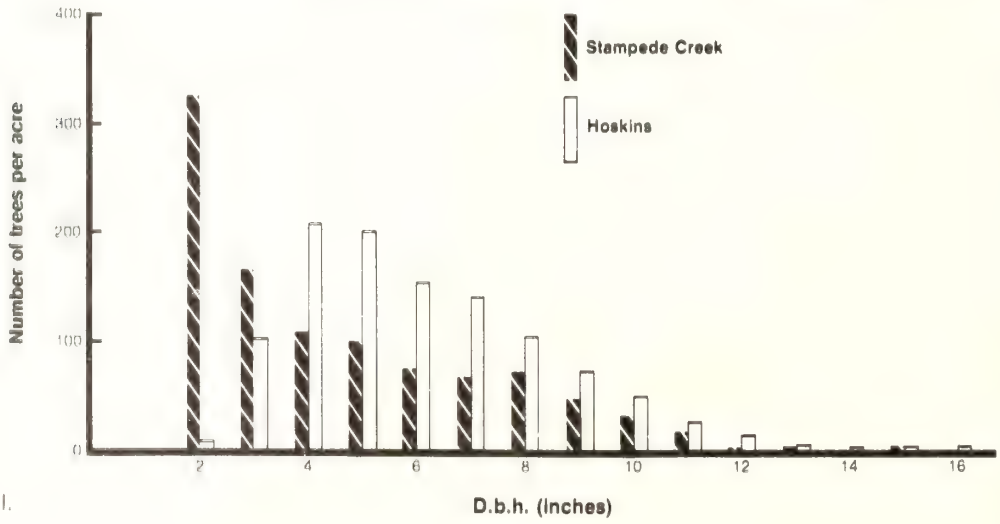
If the curve for the Stampede Creek control were extrapolated back to a height of 36 feet, it would be close to the curve at that height for the Hoskins thinning treatments and would suggest initial low density. This initial similarity in volume of the Stampede Creek control and the Hoskins thinned plots is associated with differences in the diameter distributions at the two locations. The diameter distribution for the stand at Stampede Creek at the start of the first treatment period was somewhat J-shaped, with a large number of trees in the smallest size classes. Though ranges in diameter were similar, Stampede Creek had many more trees in the smallest size classes (fig. 11). This suggests a somewhat greater range in tree ages at Stampede Creek, with greater initial crown differentiation. Such stands are common in the South Umpqua drainage.

omparison of Volume rowth Per Unit of eight Growth Relative Average Growing ock for Stands 65 Feet Height

It seems reasonable to compare growth at Stampede Creek during its first treatment period with growth at Hoskins and Iron Creek when the latter stands were of similar height (third treatment period). Volume growth should be closely related to initial height and to periodic height increment (Evert 1964), and comparisons of growth per unit of height growth are one way of removing effects of age and site differences.

Since periodic height increments were not identical nor exactly 10 feet, volume growth was expressed as gross cubic volume growth per foot of height increment for the period, when stands were about 65 feet tall at the start of the period.

Graphical comparisons of the results indicate, as expected, general similarity among installations (fig. 12). Stampede Creek appeared to have slightly more volume growth per foot of height growth, for a given initial volume. It also had slightly higher values of relative density, presumably reflecting its different structure and earlier stage in the thinning regime. These data suggest no density type III (fig. 13) as postulated by Langsaeter (Braathe 1957), and the Hoskins controls are very dense. Such a density type has been suggested for older stands (Williamson and Price 1971, Williamson 1982), and it may be that the hypothesis is more appropriately applied to older stands past the period of rapid height growth.



gure 11 — Diameter distribu-ns of control for Stampede reek at start of first treatment riod and for Hoskins at start third treatment period, when th stands were about 65 feet tall.

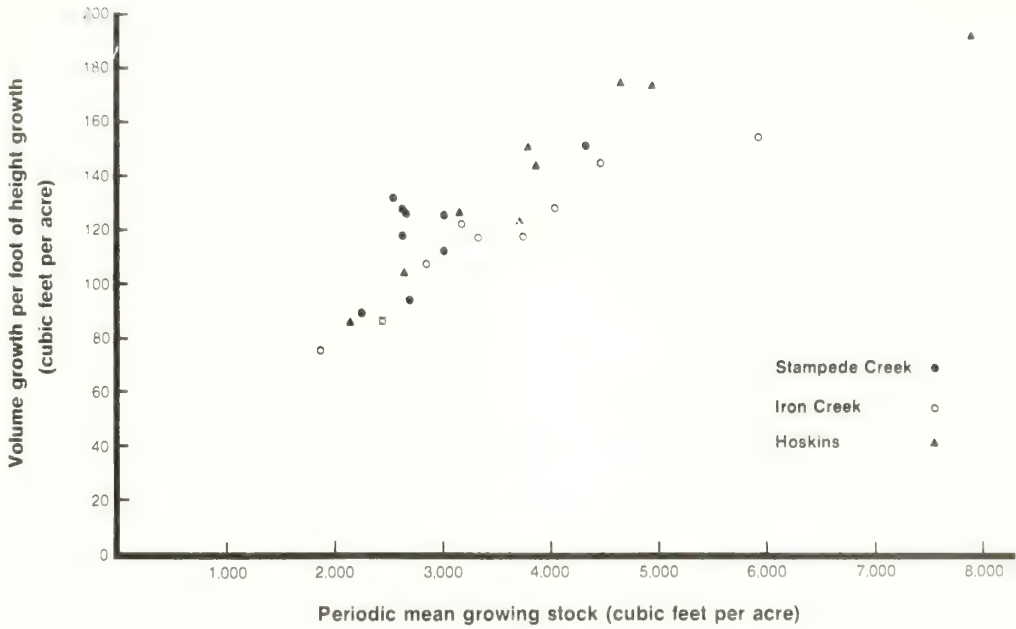


Figure 12.—Stampede Creek, Iron Creek, and Hoskins: volume growth per foot of crop tree height growth in relation to volume of growing stock, when stands were about 65 feet tall.

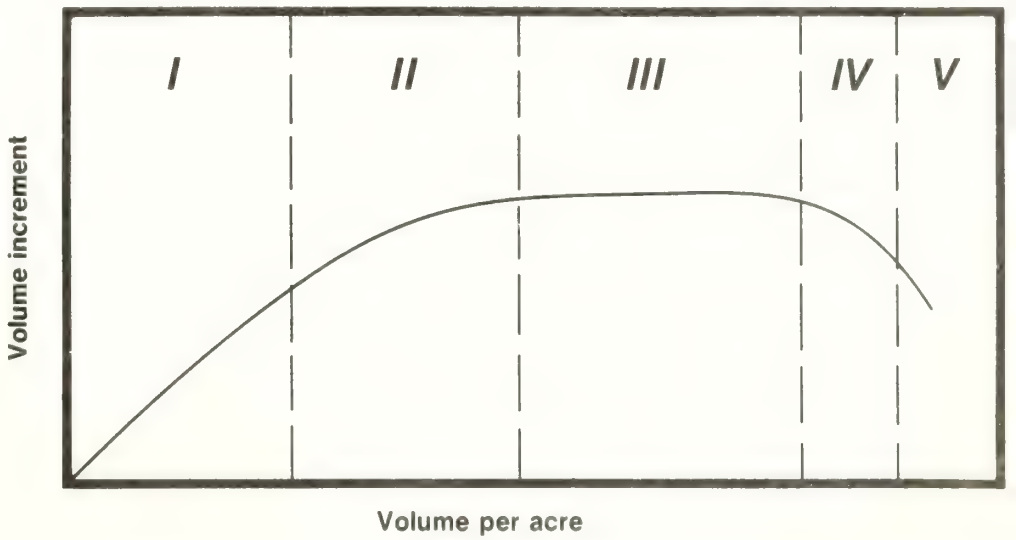


Figure 13.—Relation between standing volume and volume increment, as hypothesized by Langsaeter (prepared from Braathe 1957). Roman numerals denote Langsaeter's "density types."

Cumulative Net Production by Size Classes

Figure 14 shows cumulative yields in total volume of trees, 7.6 inches and larger, 9.6 inches and larger, and 11.6 inches and larger, at the end of the fourth treatment period in the Hoskins study. At that time, average crop tree height was 86 feet, with 50 feet of elapsed height growth since the calibration thinning.

Total production in trees 7.6 inches and larger was less on the thinned treatments than on the control, in trees 9.6 inches and larger it was about the same, and in trees 11.6 inches and larger it was roughly twice as much on the thinned treatments as on the control. Any economic evaluation depends on the premium for large size trees and on the choice of harvest age. Differences can be expected to continue to increase as stand age increases.

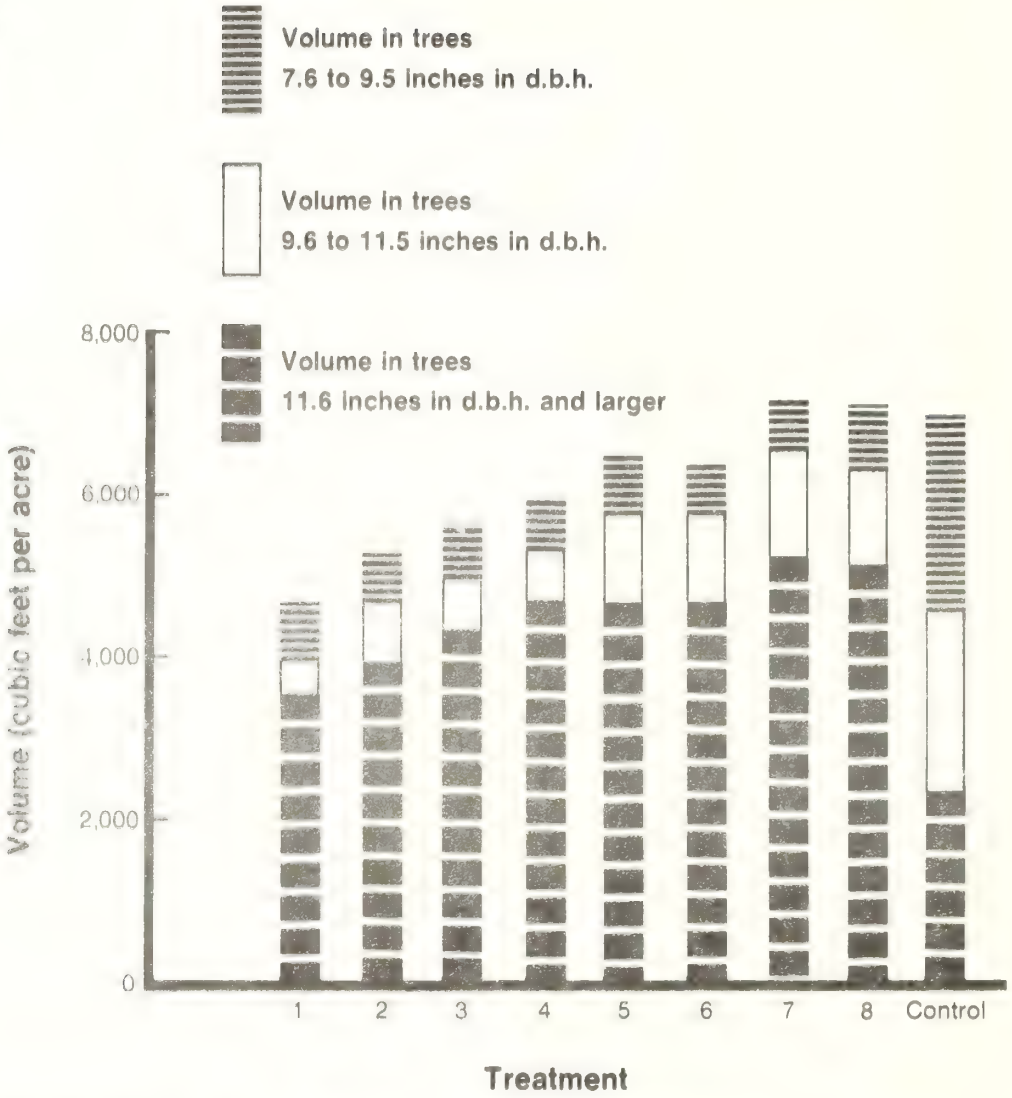


Figure 14.—Hoskins cumulative volume production for trees 11.6 inches in d.b.h. and larger and for trees 9.6 to 11.5 and 7.6 to 9.5 inches in d.b.h. at end of fourth treatment period (age 37), plus trees removed in thinnings (calibration cut excluded)

The 16 years of record on the Hoskins plots are probably a good indication of what can be expected in the future from the other studies, although the lesser initial density and less uniform nature of the Stampede Creek control may reduce the differences between thinned treatments and the control at Stampede Creek.

Discussion

Early results show that Stampede Creek differs somewhat from Iron Creek and Hoskins in the relationship of growth to growing stock and of growth of thinned stand to growth of control. Possible causes include: (1) differences in initial stand structure and stand homogeneity, (2) the later start of thinning at Stampede Creek, and (3) the evident differences in site quality and site characteristics.

Because of the later start of thinning at Stampede Creek, the thinning treatments lag behind those at the other studies, in relation to height development. This introduces some differences, but the general pattern of future development will probably be similar. In particular, relationships of growth to growing stock will be similar to those observed at Iron Creek and Hoskins, but at lower levels because o lower site quality.

To age 43, the Stampede Creek thinnings have resulted in some reduction in total production accompanied by moderate gains in diameters. In this stand and similar stands having moderate initial numbers of stems and considerable early crown differentiation, thinning probably is not economically justifiable if the objective is fiber production on very short rotations (for example, 50 years or less for this low site III stand). The large increases in tree diameters attained at Hoskins by the end of the fourth treatment period, however, indicate a different picture for longer rotations or higher sites.

The particular thinning regimes used in the LOGS studies were designed to determine growth to growing stock relationships, rather than operationally optimum regimes. Most managers would make only one precommercial thinning and would probably adopt somewhat longer intervals between commercial thinnings. The principles of growth to growing stock relationships, however, would remain much the same.

At the time the LOGS studies were established, thinking was strongly influenced by the so-called Langsaeter hypothesis (fig. 13). As stated by Braathe (1957, p. 49)

> The roman numerals [in figure 13] denote what Langsaeter called "density types". In density type I the stand is so open that the individual tree exerts no influence on its neighbours, and the annual yield is therefore proportional to the number of trees or the volume of the stand.
>
> Density type II shows a flattening curve for the annual yield; i.e., the trees are beginning to crowd each other increasingly.
>
> The broad band of type III shows an almost horizontal line for the yield curve denoting a rather wide band in which the yield is independent of stand density. Density type IV indicates a rather abrupt change to declining yield, as stand density becomes excessive and leads to declining tree vigor.
>
> This decreasing yield is even more pronounced in density type V, the condition of density where the trees have been so crowded that their resistance to disease and injury has been greatly lowered, and where pronounced stagnation results.

As shown by the growth:growing stock curves, the calibration and first treatment periods in the LOGS studies clearly fall in Langsaeter's zone I, with later thinning periods in zone II. The control plots in the later periods at Iron Creek and Hoskins are close to the maximum possible density, and there is little indication of any broad "plateau" of constant gross volume growth over a wide range of stocking. Thinnings that do much more than anticipate mortality will reduce total growth, with an offsetting gain in tree size and value.

Curves of gross volume periodic annual increment over RD resemble the growth:growing stock curves presented, except that RD provides a scale comparable across all ages. Such curves suggest that Langsaeter's zone II corresponds to RD values of about 30 to 60, and that stands maintained in the range of RD40 to RD55 represent a reasonable compromise between some loss of total volume increment and substantial gains in tree size and stand stability. Once stands reach a stage where thinnings can pay their way, this seems a reasonable stocking goal.

If an RD of 55 is attained when stand average diameter reaches 20 inches, the related basal area would be 246 square feet per acre, corresponding to about 89 percent of normal according to table 25 in McArdle and others (1961). Such a stocking goal seems reasonable for southwest Oregon, or for anywhere else within the Pacific Douglas-fir forest type (Williamson 1980).

Metric Equivalents

1 centimeter = 0.3937 inch
1 meter = 3.2808 feet
1 square meter = 10.7643 square feet
1 cubic meter = 35.3107 cubic feet
1 square meter per hectare = 4.3560 square feet per acre
1 cubic meter per hectare = 14.2918 cubic feet per acre
°C = 0.5556 (°F minus 32)

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Appendix 1

Excerpt from Report No. 1 (Williamson and Staebler 1971):

DESCRIPTION OF EXPERIMENT

The experiment is designed to test a number of thinning regimes beginning in young stands made alike at the start through a "calibration" thinning. Thereafter, through the time required for 60 feet of height growth, growing stock is controlled by allowing a specified addition to the growing stock between successive thinnings. Any extra growth is cut and is one of the measured effects of the thinning regime.

. . . . . .

Experimental Design

A single experiment consists of eight thinning regimes plus unthinned plots whose growth is the basis for treatment in these regimes. There are three plots per treatment arranged in a completely randomized design for a total of twenty-seven 1/5-acre plots. . . .

Interaction of site quality and treatment can be evaluated by replicating installations on each site quality class. Cooperative effort has made this replication possible.

Crop Tree Selection

Well formed, uniformly spaced, dominant trees at the rate of 80 per acre, or 16 per plot, are designated as crop trees prior to initial thinning. Each quarter of a plot must have no fewer than three suitable crop trees nor more than five—another criterion for stand uniformity.

Initial or "Calibration" Thinning

All 24 treated plots are thinned initially to the same density to minimize the effect of variations in original density on stand growth. Density of residual trees is controlled by quadratic mean diameter [diameter of tree of average basal area] of the *residual* stand according to the formula:

Average spacing in feet = 0.6167 (quadratic mean d.b.h.) + 8.

. . . . . .

If one concentrates on leaving a certain amount of basal area corresponding to an estimated overall quadratic mean d.b.h. . . . [Dg], then the residual number of trees may vary freely and the actual . . . [Dg's] may vary between plots. . . ±10 percent. Alternatively, if emphasis is on leaving a certain number of trees corresponding to an estimated overall. . . [Dg], then the basal area may vary and the actual. . . [Dg's] may vary. . . ±15 percent between plots.

. . . . . .

Treatments

The eight thinning regimes tested differ in the amount of basal area allowed to accumulate in the growing stock. The amount of growth retained at any thinning is a predetermined percentage of the gross increase found in the unthinned plots since the last thinning...[table inside front cover]. The average residual basal area for all thinned plots after the calibration thinning is the foundation upon which all future growing stock accumulation is based. As used in the study, control plots may be thought of as providing a "local gross yield table" for the study area.

Control of Thinning Interval

Thinnings will be made [after the calibration thinning] whenever average height growth of crop trees...comes closest to each multiple of 10 feet [above the initial height].

Control of Type of Thinning

As far as possible, type of thinning is eliminated as a variable in the treatment thinnings through several specifications:

1. No crop tree may be cut until all noncrop trees have been cut (another tree may be substituted for a crop tree damaged by logging or killed by natural agents).
2. The quadratic mean diameter of cut trees should approximate that of trees that are available for cutting.
3. The diameters of cut trees should be distributed across the full diameter range of trees available for cutting.

Appendix 2

Tables 5 to 10—summary data for live stand, periodic annual growth, and cut tree
Stampede Creek

Tables 11 to 15—summary data for live stand and periodic annual growth: Iron Cre

Table 5—Stampede Creek: stand data for all live trees, by treatment, at beginning and end of period—1968-73 and 1973-78

	Trees per acre				Quadratic mean d.b.h.				Basal area per acre				Total stem volume per acre			
	Calibration		1st treatment		Calibration		1st treatment		Calibration		1st treatment		Calibration		1st treatment	
Treatment	1968	1973	1973	1978	1968	1973	1973	1978	1968	1973	1973	1978	1968	1973	1973	1978
	Number				Inches				Square feet				Cubic feet			
1	293	292	192	190	6.6	7.9	8.4	9.9	68.7	98.4	73.2	100.5	1,475	2,448	1,868	2,975
2	287	283	190	187	6.6	7.9	8.3	9.8	67.5	96.0	71.8	97.5	1,440	2,389	1,837	2,789
3	288	287	197	197	6.7	7.9	8.6	10.0	69.6	98.9	78.8	107.1	1,466	2,440	2,004	3,147
4	295	290	207	203	6.6	7.9	8.4	9.9	69.7	99.2	79.5	107.5	1,448	2,469	2,037	3,125
5	283	282	235	235	6.7	8.0	8.2	9.5	68.9	97.6	86.4	114.6	1,505	2,482	2,238	3,364
6	320	317	278	275	6.1	7.4	7.5	8.9	64.7	94.4	85.8	119.0	1,318	2,212	2,031	3,284
7	278	277	258	250	6.7	8.0	8.1	9.5	68.8	97.5	92.9	122.0	1,544	2,510	2,403	3,629
8	255	253	235	233	7.0	8.3	8.5	9.7	67.5	95.6	91.8	120.3	1,498	2,518	2,441	3,597
Control	997	1,010	1,010	887	4.7	5.3	5.3	6.1	119.2	152.0	152.0	181.9	2,354	3,557	3,557	4,905

Table 6—Stampede Creek: stand data for crop trees, by treatment, at beginning and end of period—1968-73 and 1973-78

	Trees per acre				Quadratic mean d.b.h.				Basal area per acre				Total stem volume per acre			
	Calibration		1st treatment		Calibration		1st treatment		Calibration		1st treatment		Calibration		1st treatment	
Treatment	1968	1973	1973	1978	1968	1973	1973	1978	1968	1973	1973	1978	1968	1973	1973	1978
	Number				Inches				Square feet				Cubic feet			
1	80	80	80	80	8.3	10.0	10.0	11.7	30.0	43.4	43.4	59.7	713	1,182	1,182	1,871
2	80	80	80	78	8.8	10.6	10.6	12.5	33.9	48.6	48.9	66.5	802	1,340	1,349	2,047
3	80	80	80	80	8.4	10.0	10.0	11.7	30.6	43.9	43.9	59.7	705	1,191	1,191	1,850
4	80	80	80	80	8.3	10.1	10.1	11.8	30.3	44.3	44.3	60.7	694	1,216	1,216	1,878
5	80	80	80	80	9.1	10.8	10.8	12.5	36.2	51.2	51.2	67.8	885	1,471	1,471	2,164
6	80	80	80	80	8.0	9.8	9.8	11.5	28.0	41.4	41.4	57.6	645	1,076	1,076	1,739
7	80	80	80	80	8.4	10.1	10.1	11.6	30.8	44.4	44.4	58.8	740	1,236	1,236	1,882
8	80	80	80	80	8.9	10.7	10.7	12.3	34.6	49.9	49.9	66.3	827	1,462	1,462	2,167
Control	80	80	80	80	8.7	10.1	10.1	11.5	33.0	44.8	44.8	57.6	790	1,254	1,254	1,849

Table 7—Stampede Creek: periodic annual growth, total growth, and cumulative volume yield for all trees, by treatment and period—1968-73 and 1973-78

Treatment	Quadratic mean d.b.h.			Basal area		
	Periodic annual net growth			Periodic annual gross growth		
	Calibration, 1968-73	1st treatment, 1973-78	Total growth, 1968-78	Calibration, 1968-73	1st treatment, 1973-78	Total growth, 1968-78
	Inches			Square feet per acre		
1	0.26	0.29	2.7	6.0	5.5	57.5
2	.26	.28	2.7	5.8	5.3	55.9
3	.26	.28	2.7	5.9	5.7	57.9
4	.26	.28	2.7	6.0	5.7	58.6
5	.25	.25	2.5	5.8	5.6	57.0
6	.26	.27	2.6	6.0	6.7	63.4
7	.26	.24	2.5	5.7	6.0	58.8
8	.27	.25	2.6	5.6	5.8	57.0
Control	.09	.11	1.0	6.9	6.9	69.3

Treatment	Total stem volume			
	Periodic annual gross growth		Cumulative yield	
	Calibration, 1968-73	1st treatment, 1973-78	Calibration, 1973	1st treatment, 1978
	Cubic feet per acre			
1	196	222	2,456	3,564
2	193	195	2,407	3,383
3	196	229	2,448	3,591
4	207	222	2,481	3,593
5	196	225	2,484	3,610
6	179	251	2,215	3,472
7	193	249	2,511	3,754
8	204	233	2,518	3,684
Control	246	285	3,584	5,009

Table 8—Stampede Creek: periodic annual growth, total growth, and cumulative volume yield for crop trees, by treatment and period—1968-73 and 1973-78

Treatment	Quadratic mean d.b.h.			Basal area		
	Periodic annual net growth			Periodic annual gross growth		
	Calibration, 1968-73	1st treatment, 1973-78	Total growth, 1968-78	Calibration, 1968-73	1st treatment, 1973-78	Total growth, 1968-78
	- - - Inches - - -			- - - - Square feet per acre - - - -		
1	0.33	0.35	3.4	2.7	3.3	29.7
2	.35	.36	3.5	3.0	3.6	32.9
3	.33	.33	3.3	2.7	3.2	29.0
4	.35	.34	3.4	2.8	3.3	30.3
5	.35	.33	3.4	3.0	3.3	31.6
6	.35	.35	3.5	2.7	3.2	29.6
7	.34	.30	3.2	2.7	2.9	28.0
8	.36	.33	3.4	3.1	3.3	31.7
Control	.29	.27	2.8	2.4	2.6	24.6

	Total stem volume				
	Periodic annual gross growth			Cumulative yield	
	Calibration, 1968-73	1st treatment, 1973-78	Total growth, 1968-78	Calibration, 1973	1st treatment, 1973
	- - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - -				
1	94	138	1,159	1,182	1,871
2	108	142	1,249	1,340	2,052
3	97	132	1,145	1,191	1,850
4	104	132	1,184	1,216	1,878
5	117	139	1,278	1,471	2,164
6	86	133	1,094	1,076	1,739
7	99	129	1,142	1,236	1,882
8	127	141	1,339	1,462	2,167
Control	93	119	1,059	1,254	1,849

Table 9—Stampede Creek: trees cut, by treatment and thinning—1973 and 1978

Treatment	Trees per acre		Quadratic mean d.b.h.		Basal area per acre		Total stem volume per acre	
	1973	1978	1973	1978	1973	1978	1973	1978
	- - Number- -		- - - -Inches - - -		- Square feet -		- -Cubic feet - -	
1	100	62	6.8	8.7	25.2	25.3	580	699
2	93	62	6.9	7.8	24.1	20.6	553	521
3	90	42	6.4	8.6	20.1	16.8	437	456
4	83	47	6.5	8.4	19.3	18.0	432	482
5	47	32	6.6	8.6	11.1	12.9	244	353
6	38	57	6.4	7.9	8.6	19.4	180	494
7	18	20	6.8	8.5	4.6	7.9	107	218
8	18	25	6.1	8.1	3.7	9.0	77	238

Table 10—Stampede Creek: mean height of crop trees by treatment and measurement year—1968, 1973, and 1978

Treatment	Trees measured			Mean height		
	1968	1973	1978	1968	1973	1978
	- - Number - -			- - - - Feet - - -		
1	11	19	31	56.2	67.3	76.2
2	13	16	33	56.5	67.0	78.0
3	12	14	31	55.2	68.0	76.9
4	11	16	32	57.6	68.5	77.3
5	14	18	35	57.1	67.5	79.7
6	13	15	28	55.0	65.3	75.9
7	10	16	31	56.0	67.9	77.8
8	10	16	31	57.9	69.4	79.8
Control	12	16	24	57.7	69.1	78.4
Thinned treatments only	94	130	252	56.4	67.6	77.7
All treatments	106	146	276	56.5	67.8	77.8
Standard deviation				1.01	1.14	1.31

Table 11—Iron Creek: stand data for all live trees, by treatment, at beginning and end of period—1966-70, 1970-73, 1973-77, 1977-80

	Trees per acre								Quadratic mean d.b.h.							
	Calibration		1st treatment		2d treatment		3d treatment		Calibration		1st treatment		2d treatment		3d treatment	
Treatment	1966	1970	1970	1973	1973	1977	1977	1980	1966	1970	1970	1973	1973	1977	1977	1980
	Number								Inches							
1	355	343	223	210	152	145	100	97	4.7	6.4	6.6	8.1	8.3	10.2	10.6	11.9
2	360	347	198	188	155	153	127	123	5.0	6.7	6.9	8.4	8.5	10.4	10.6	11.8
3	348	340	248	237	193	188	162	160	4.9	6.6	6.8	8.2	8.3	10.0	10.1	11.3
4	362	353	242	227	195	190	178	177	5.0	6.7	6.9	8.4	8.5	10.3	10.4	11.5
5	347	338	277	273	242	237	227	227	5.1	6.7	6.9	8.2	8.3	9.9	9.9	10.8
6	360	343	307	295	252	247	203	202	4.8	6.5	6.6	7.9	8.0	9.6	9.6	10.7
7	360	347	333	317	305	297	297	293	5.0	6.7	6.7	7.9	8.0	9.4	9.4	10.2
8	352	345	313	290	275	273	257	250	5.1	6.8	6.9	8.2	8.3	9.7	9.8	10.7
Control	1,128	1,193	1,193	1,192	1,192	1,183	1,183	1,095	3.7	4.5	4.5	5.1	5.1	5.1	5.7	6.2

	Basal area per acre								Total stem volume per acre							
	Calibration		1st treatment		2d treatment		3d treatment		Calibration		1st treatment		2d treatment		3d treatment	
	1966	1970	1970	1973	1973	1977	1977	1980	1966	1970	1970	1973	1973	1977	1977	1980
	Square feet								Cubic feet							
1	43.4	76.0	52.9	74.5	57.1	82.7	60.9	74.7	600	1,370	964	1,552	1,205	2,020	1,505	2,087
2	48.6	84.4	51.6	72.2	60.6	89.9	77.5	94.0	735	1,638	1,013	1,659	1,404	2,344	2,031	2,763
3	46.3	79.9	61.9	86.1	72.0	102.1	90.7	111.5	648	1,474	1,151	1,834	1,539	2,592	2,308	3,168
4	49.5	86.2	63.2	86.6	77.2	110.4	104.7	126.8	771	1,703	1,272	1,970	1,761	2,899	2,752	3,762
5	48.6	82.6	71.3	99.7	91.3	125.3	120.7	145.3	733	1,588	1,383	2,236	2,055	3,297	3,178	4,293
6	45.4	79.0	71.9	100.0	87.2	123.1	103.3	125.9	629	1,428	1,303	2,085	1,822	3,070	2,584	3,562
7	49.2	83.7	80.7	108.9	104.9	142.6	142.6	167.2	734	1,590	1,634	2,447	2,378	3,739	3,739	4,649
8	49.2	86.7	80.9	106.5	102.6	140.9	133.9	156.5	763	1,667	1,562	2,364	2,282	3,589	3,419	4,464
Control	82.4	129.9	129.9	156.5	166.5	209.4	209.4	228.2	1,115	2,328	2,328	3,[illegible]	3,510	5,170	5,170	6,404

Table 12—Iron Creek: stand data for crop trees, by treatment, at beginning and end of period—1966-70, 1970-73, 1973-77, 1977-80

	Trees per acre								Quadratic mean d.b.h.							
	Calibration		1st treatment		2d treatment		3d treatment		Calibration		1st treatment		2d treatment		3d treatment	
Treatment	1966	1970	1970	1973	1973	1977	1977	1980	1966	1970	1970	1973	1973	1977	1977	1980
	Number								Inches							
1	80	77	78	75	75	72	72	72	5.6	7.5	7.4	9.1	9.1	11.1	11.1	12.4
2	80	77	80	73	73	73	73	73	5.8	7.7	7.7	9.3	9.2	11.2	11.1	12.4
3	80	80	80	78	78	77	77	77	5.9	7.8	7.8	9.2	9.2	11.0	11.0	12.2
4	80	78	80	75	77	77	77	75	5.9	7.8	7.8	9.3	9.3	11.2	11.2	12.4
5	80	80	80	80	78	77	78	77	6.1	8.0	8.0	9.5	9.5	11.2	11.2	12.4
6	80	78	80	80	80	78	77	75	5.7	7.6	7.5	9.0	9.0	10.8	10.8	12.0
7	78	77	78	72	77	77	77	75	5.7	7.5	7.5	9.0	8.9	10.5	10.5	11.5
8	78	77	78	70	80	80	82	82	6.0	8.0	8.0	9.6	9.4	11.1	11.1	12.1
Control	78	78	78	78	78	77	76	77	5.8	7.4	7.4	8.8	8.6	9.7	9.7	10.4

	Basal area per acre								Total stem volume per acre							
	Calibration		1st treatment		2d treatment		3d treatment		Calibration		1st treatment		2d treatment		3d treatment	
	1966	1970	1970	1973	1973	1977	1977	1980	1966	1970	1970	1973	1973	1977	1977	1980
	Square feet								Cubic feet							
1	13.6	29.3	22.[illegible]	33.6	33.6	44.[illegible]	49.1	[illegible]	2[illegible]	44[illegible]	44[illegible]	[illegible]	2[illegible]	[illegible]	1,230	1,699
2	14.9	29.7	25.[illegible]	34.[illegible]	34.[illegible]	49.8	51.7	61.5	2[illegible]	50[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,367	1,823
3	15.2	26.4	26.3	36.4	36.3	50.8	50.8	62.6	227	517	[illegible]	[illegible]	796	[illegible]	1,312	1,807
4	15.2	26.3	26.6	[illegible]	36.5	[illegible]	52.5	[illegible]	253	552	557	[illegible]	[illegible]	[illegible]	1,483	1,895
5	16.2	27.0	28.1	[illegible]	38.7	52.9	52.9	63.8	258	563	570	[illegible]	[illegible]	827	1,427	1,942
6	14.0	24.5	24.8	[illegible]	35.1	49.5	48.7	59.2	207	[illegible]	4[illegible]	769	759	[illegible]	[illegible]	1,726
7	13.9	23.7	24.0	[illegible]	33.4	46.4	46.4	54.3	217	460	[illegible]	726	168	[illegible]	1,245	1,644
8	15.2	26.8	27.2	[illegible]	38.8	53.9	55.2	65.6	247	[illegible]	[illegible]	[illegible]	905	[illegible]	1,458	1,927
Control	14.4	23.4	23.4	[illegible]	31.2	[illegible]	40.3	45.7	[illegible]	459	[illegible]	[illegible]	717	1,062	1,082	[illegible]

Table 13—Iron Creek: periodic annual growth and cumulative volume yield for all trees, by treatment and period—1966-70, 1970-73, 1973-77, 1977-80

Treatment	Quadratic mean d.b.h., periodic annual net growth				Basal area, periodic annual gross growth			
	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80
	Inch				Square feet per acre			
1	0.40	0.46	0.45	0.44	8.5	8.3	6.8	5.3
2	.41	.48	.46	.40	9.4	7.9	7.4	6.2
3	.40	.45	.42	.38	8.6	9.0	8.0	7.1
4	.41	.45	.43	.36	9.4	9.1	8.5	7.7
5	.40	.43	.37	.32	8.8	9.9	8.9	8.2
6	.40	.43	.39	.34	8.8	10.3	9.3	7.8
7	.40	.41	.34	.27	9.0	10.8	9.8	8.7
8	.42	.43	.36	.28	9.6	11.0	9.6	8.0
Control	.19	.18	.12	.09	12.1	12.9	11.9	9.1

	Periodic annual gross growth				Cumulative yield			
	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80
	Cubic feet per acre				Cubic feet per acre			
1	197	216	213	213	1,389	2,038	2,889	3,528
2	234	240	237	266	1,673	2,391	3,338	4,136
3	210	246	275	293	1,487	2,227	3,327	4,206
4	238	262	289	345	1,721	2,506	3,663	4,698
5	218	293	320	372	1,606	2,486	3,765	4,880
6	206	277	318	331	1,454	2,286	3,559	4,553
7	221	333	355	424	1,620	2,617	4,039	5,310
8	229	320	328	360	1,678	2,639	3,953	5,034
Control	307	406	442	480	2,342	3,562	5,329	6,769

Table 14—Iron Creek: periodic annual growth and cumulative volume yield for crop trees, by treatment and period—1966-70, 1970-73, 1973-77, 1977-80

Treatment	Quadratic mean d.b.h., periodic annual net growth				Basal area periodic annual gross growth			
	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80
	Inch				Square feet per acre			
1	0.45	0.51	0.48	0.45	2.5	3.6	3.9	4.2
2	.44	.51	.48	.41	2.6	3.8	3.9	4.0
3	.47	.49	.45	.41	2.8	3.6	3.9	3.9
4	.47	.49	.46	.39	2.8	3.7	3.9	3.8
5	.47	.49	.42	.37	2.9	3.7	3.7	3.6
6	.47	.50	.44	.39	2.7	3.6	3.8	3.7
7	.45	.45	.40	.32	2.5	3.1	3.2	2.9
8	.50	.49	.42	.33	3.0	3.6	3.8	3.5
Control	.40	.39	.30	.25	2.2	2.6	2.4	2.2

	Periodic annual gross growth				Cumulative yield			
	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment, 1977-80	Calibration, 1966-70	1st treatment, 1970-73	2d treatment, 1973-77	3d treatment 1977-80
	Cubic feet per acre							
1	62	100	125	167	449	749	1,251	1,751
2	69	116	128	174	514	864	1,377	1,900
3	71	101	136	165	512	817	1,360	1,855
4	76	109	135	172	555	882	1,421	1,938
5	76	116	134	172	563	911	1,448	1,963
6	65	101	133	162	468	770	1,302	1,787
7	63	100	119	142	468	769	1,245	1,670
8	76	111	130	156	550	884	1,406	1,875
Control	61	86	95	116	459	717	1,096	1,443

Table 15—Iron Creek: mean height of crop trees, by treatment and measurement year—1966, 1970, 1973, 1977, and 1980

Treatment	Trees measured					Mean height				
	1966	1970	1973	1977	1980	1966	1970	1973	1977	1980
	Number					Feet				
1	16	22	21	28	32	34.4	45.9	53.5	63.6	71.9
2	16	22	21	30	30	36.4	48.7	56.4	66.3	75.6
3	16	24	23	31	30	34.9	47.0	53.9	64.6	72.8
4	15	22	23	28	26	38.8	50.5	58.5	68.6	77.4
5	15	22	19	30	30	37.6	48.9	57.3	67.5	77.0
6	15	21	22	27	28	35.4	45.8	53.2	64.6	72.8
7	16	24	24	30	27	36.7	46.7	55.2	67.3	76.1
8	15	21	20	30	29	38.4	49.6	57.7	66.5	75.1
Control	14	19	18	20	20	35.4	47.5	55.7	65.9	75.1
Thinned only	124	178	173	234	232	36.6	47.9	55.7	66.1	74.8
All treatments	138	197	191	254	252	36.4	47.8	55.7	66.1	74.8
Standard deviation						1.47	1.58	1.83	1.52	1.87

Appendix 3

Tables 16 to 24—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatments 1 through 9 at beginning and end of period—1968 to 1973

Tables 25 to 33—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatments 1 through 9 at end of period—1978

Table 16—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 1 at beginning and end of period—1968-73

D.b.h. class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	- - -Number- - -				- - - - Cubic feet - - - -				- Percent -		- Cubic feet -		- -Percent - -	
13.6 - 14.5		2		2		33.9		56.6		2.3		56.6		2.3
12.6 - 13.5		3		5		27.1		90.3		3.7		146.9		6.0
11.6 - 12.5	2	3	2	8	23.1	22.7	38.4	75.6	2.61	3.1	38.4	222.5	2.6	9.1
10.6 - 11.5	2	12	3	20	18.0	18.5	30.0	216.3	2.03	8.8	68.4	438.8	4.6	17.9
9.6 - 10.5	5	35	8	55	14.7	14.9	73.3	522.3	4.97	21.3	141.7	961.0	9.6	39.2
8.6 - 9.5	23	48	32	103	10.7	11.3	249.6	545.2	16.93	22.3	391.3	1,506.2	26.5	61.5
7.6 - 8.5	42	50	73	153	8.0	8.8	332.9	440.3	22.58	18.0	724.2	1,946.6	49.1	79.5
6.6 - 7.5	65	37	138	190	5.8	6.1	379.3	224.2	25.72	9.2	1,103.5	2,170.8	74.8	88.7
5.6 - 6.5	48	42	187	232	3.9	4.0	189.7	165.9	12.87	6.8	1,293.3	2,336.7	87.7	95.4
4.6 - 5.5	48	25	235	257	2.4	2.7	114.3	66.5	7.75	2.7	1,407.5	2,403.2	95.5	98.2
3.6 - 4.5	38	22	273	278	1.4	1.6	54.8	33.7	3.72	1.4	1,462.3	2,437.0	99.2	99.5
2.6 - 3.5	18	13	292	292	.6	.8	11.5	11.3	.78	.5	1,473.8	2,448.3	99.9	100.0
1.6 - 2.5	2		293		.4		.7		.05		1,474.5		100.0	
Total	293	292					1,474.5	2,448.3	100.0	100.0				
Average					5.0	8.4								

1/ Rounded to whole numbers.

Table 17—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 2 at beginning and end of period—1968-73

D.b.h. class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	- - - Number- - - -				- - - - - Cubic feet - - -				- Percent -		- Cubic feet -		- Percent -	
15.6 - 16.5		2		2		51.2		85.3		3.6		85.3		3.6
14.6 - 15.5		2		3		44.7		74.5		3.1		159.8		6.7
13.6 - 14.5	2	5	2	8	34.0	33.8	57.7	169.0	4.0	7.1	57.7	328.8	4.0	13.8
12.6 - 13.5	2	5	3	13	26.8	26.6	44.7	133.1	3.1	5.6	102.4	462.0	7.1	19.3
11.6 - 12.5	5	12	8	25	21.4	21.1	106.8	246.7	7.4	10.3	209.2	708.6	14.5	29.7
10.6 - 11.5	5	13	13	38	16.2	18.8	80.8	250.3	5.6	10.5	290.0	958.9	20.1	40.1
9.6 - 10.5	13	28	27	67	12.9	14.0	171.8	396.0	11.9	16.6	461.9	1,354.9	32.1	56.7
8.6 - 9.5	18	20	45	87	10.5	10.5	193.3	209.5	13.4	8.8	655.1	1,564.4	45.5	65.5
7.6 - 8.5	27	33	72	120	7.7	8.5	204.7	281.9	14.2	11.8	859.8	1,846.3	59.7	77.3
6.6 - 7.5	42	30	113	150	5.4	5.9	223.4	177.3	15.5	7.4	1,083.2	2,023.6	75.2	84.7
5.6 - 6.5	43	48	157	198	3.7	4.1	161.4	197.1	11.2	8.2	1,244.6	2,220.7	86.4	93.0
4.6 - 5.5	42	43	198	242	2.3	2.7	96.7	116.0	6.7	4.8	1,341.3	2,336.7	93.1	97.8
3.6 - 4.5	52	30	250	272	1.4	1.4	74.4	42.7	5.2	1.8	1,415.8	2,379.4	98.3	99.6
2.6 - 3.5	35	12	287	284	.7	.8	24.0	9.7	1.7	.4	1,439.8	2,389.1	99.9	100.0
1.6 - 2.5	2				.3		.6		.0		1,440.4		100.0	
Total	287	283					1,440.4	2,389.1	100.0	100.0				
Average					5.0	8.4								

1/ Rounded to whole numbers.

Table 18—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 3 at beginning and end of period—1968-73

D.b.h. class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	Number				Cubic feet				Percent		Cubic feet		Percent	
13.6 - 14.5		2		2		32.9		54.8		2.2		54.8		2.2
12.6 - 13.5		0		2		0		0		0		54.8		2.2
11.6 - 12.5	2	7	2	8	20.9	22.9	34.8	152.8	2.4	6.3	34.8	207.6	2.4	8.5
10.6 - 11.5	0	27	2	35	0	18.4	0	489.4	0	20.0	34.8	697.0	2.4	28.6
9.6 - 10.5	8	17	10	52	13.7	14.8	114.1	246.3	7.8	10.1	148.9	943.3	10.2	38.6
8.6 - 9.5	28	48	38	100	10.8	11.0	306.2	532.5	20.9	21.8	455.1	1,475.8	31.0	60.5
7.6 - 8.5	30	55	68	155	7.7	8.6	231.4	473.3	15.8	19.4	686.5	1,949.1	46.8	79.9
6.6 - 7.5	73	38	142	193	5.6	6.0	410.0	229.3	28.0	9.4	1,096.6	2,178.4	74.8	89.3
5.6 - 6.5	50	35	192	228	3.9	4.0	193.6	139.5	13.2	5.7	1,290.2	2,318.0	88.0	95.0
4.6 - 5.5	43	33	235	262	2.5	2.7	107.0	89.0	7.3	3.6	1,397.2	2,407.0	95.3	98.6
3.6 - 4.5	40	20	275	282	1.5	1.5	60.2	30.0	4.1	1.2	1,457.4	2,437.0	99.4	99.9
2.6 - 3.5	13	5	288	287	.7	.7	9.0	3.4	.6	.1	1,466.5	2,440.4	100.0	100.0
Total	288	287					1,466.5	2,440.4	100.0	100.0				
Average					5.1	8.5								

1/ Rounded to whole numbers.

Table 19—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 4 at beginning and end of period—1968-73

D.b.h. class	Trees per acre 1/		Cumulative trees per tree		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	Number				Cubic feet				Percent		Cubic feet		Percent	
11.6 - 12.5		8		8		22.9		190.8		7.7		190.8		7.7
10.6 - 11.5		20		28		18.6		371.8		15.1		562.6		22.8
9.6 - 10.5	8	38	8	67	13.8	14.8	115.0	567.8	7.9	23.0	115.0	1,130.3	7.9	45.8
8.6 - 9.5	23	33	32	100	10.6	11.4	247.5	379.8	17.1	15.4	362.6	1,510.2	25.0	61.2
7.6 - 8.5	48	40	80	140	8.0	8.5	384.3	338.9	26.5	13.7	746.9	1,849.1	51.6	74.9
6.6 - 7.5	53	58	133	198	5.6	6.2	299.4	360.1	20.7	14.6	1,046.3	2,209.2	72.2	89.5
5.6 - 6.5	62	42	195	240	3.7	4.0	228.2	167.6	15.8	6.8	1,274.4	2,376.8	88.0	96.2
4.6 - 5.5	48	22	243	262	2.5	2.7	120.4	57.5	8.3	2.3	1,394.8	2,434.3	96.3	98.6
3.6 - 4.5	28	17	272	278	1.4	1.6	38.7	26.2	2.7	1.1	1,433.5	2,460.5	99.0	99.6
2.6 - 3.5	20	12	292	290	.7	.8	13.7	9.0	1.0	.4	1,477.2	2,469.5	99.9	100.0
1.6 - 2.5	3		295		.3		1.0		.1		1,448.2		100.0	
Total	295	290					1,448.2	2,469.5	100.0	100.0				
Average					4.9	8.5								

1/ Rounded to whole numbers.

Table 20—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 5 at beginning and end of period—1968-73

D.b.h. class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	- - - - Number - - - -				- - - - Cubic feet - - - -				- Percent -		- Cubic feet -		- Percent -	
14.6 - 15.5		3		3		40.6		135.5		5.5		135.5		5.5
13.6 - 14.6		2		5		37.7		62.8		2.5		198.3		8.0
12.6 - 13.5	2	8	2	13	26.2	28.2	43.7	236.1	2.9	9.5	43.7	433.4	2.9	17.5
11.6 - 12.5	3	10	5	23	23.3	24.9	77.5	248.6	5.2	10.0	121.2	682.0	8.0	27.5
10.6 - 11.5	13	20	18	43	17.0	19.4	226.2	387.9	15.0	15.6	347.4	1,069.9	23.1	43.1
9.6 - 10.5	10	12	28	55	13.3	14.0	133.5	163.5	8.9	6.6	480.9	1,233.3	32.0	49.7
8.6 - 9.5	15	37	43	92	11.4	11.5	170.4	421.1	11.3	17.0	651.3	1,654.4	43.3	66.7
7.6 - 8.5	28	37	72	128	7.8	8.4	219.8	309.1	14.6	12.4	871.1	1,963.5	57.9	79.1
6.6 - 7.5	45	32	117	160	5.8	6.1	259.2	191.9	17.2	7.7	1,130.3	2,155.4	75.1	86.8
5.6 - 6.5	40	47	157	207	4.0	3.9	158.6	183.2	10.5	7.4	1,288.8	2,338.6	85.6	94.2
4.6 - 5.5	55	40	212	247	2.5	2.6	134.9	102.9	9.0	4.2	1,423.8	2,441.6	94.6	98.4
3.6 - 4.5	47	22	258	268	1.4	1.5	66.6	31.9	4.4	1.3	1,490.4	2,473.4	99.0	99.7
2.6 - 3.5	18	13	277	282	.7	.6	12.8	8.5	.8	.3	1,503.1	2,481.9	99.9	100.0
1.6 - 2.5	7		283		.3		2.2		.1		1,505.3		100.0	
Total	283	282					1,505.3	2,481.9	100.0	100.0				
Average					5.3	8.8								

1/ Rounded to whole numbers.

Table 21—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 6 at beginning and end of period—1968-73

D.b.h. class	Trees per acre 1/		Cumulative trees per tree		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	- - - - Number - - -				- - - - -Cubic feet - - - -				- Percent -		- Cubic feet -		- Percent -	
13.6 - 14.6		3		3		30.9		102.9		4.6		102.9		4.6
12.6 - 13.5		2		5		26.3		43.9		2.0		146.8		6.6
11.6 - 12.5	3	3	3	8	21.1	23.9	70.2	79.8	5.3	3.6	70.2	226.6	5.3	10.2
10.6 - 11.5	2	12	5	20	15.4	17.2	25.7	200.8	2.0	9.1	95.8	427.3	7.3	19.3
9.6 - 10.5	5	23	10	43	14.6	14.4	73.0	335.0	5.5	15.2	168.8	762.3	12.8	34.5
8.6 - 9.5	10	43	20	87	10.2	10.7	102.4	465.3	7.8	21.0	271.2	1,227.6	20.6	55.5
7.6 - 8.5	38	40	58	127	8.1	8.0	308.9	321.5	23.4	14.5	580.1	1,549.1	44.0	70.0
6.6 - 7.5	48	47	107	173	5.6	5.7	270.3	267.2	20.5	12.1	850.4	1,816.3	64.5	82.1
5.6 - 6.5	62	52	168	225	3.7	4.1	228.8	209.3	17.4	9.5	1,079.3	2,025.6	81.9	91.6
4.6 - 5.5	52	50	220	275	2.4	2.5	124.2	126.1	9.4	5.7	1,203.5	2,151.7	91.3	97.3
3.6 - 4.5	67	35	287	310	1.4	1.5	90.9	53.8	6.9	2.4	1,294.4	2,205.5	98.2	99.7
2.6 - 3.5	33	7	320	317	.7	.9	23.6	6.2	1.8	.3	1,318.0	2,211.7	100.0	100.0
Total	320	317					1,318.0	2,211.7	100.0	100.0				
Average					4.1	7.0								

1/ Rounded to whole numbers.

Table 22—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 7 at beginning and end of period—1968-73

D.b.h class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	-----	Number	----		-----	Cubic feet	----		- Percent -		-- Cubic feet --		- Percent-	
12.6 - 13.5		8		8		27.8		231.3		9.2		231.3		9.2
11.6 - 12.5		9		17		23.5		195.6		7.8		426.9		17.0
10.6 - 11.5	8	12	8	28	17.5	18.4	146.1	215.0	9.5	8.6	146.1	641.8	9.5	25.6
9.6 - 10.5	9	18	17	47	13.5	15.1	112.9	277.6	7.3	11.1	259.0	919.4	16.8	36.6
8.6 - 9.5	18	52	35	98	10.6	11.7	193.6	602.6	12.5	24.0	452.5	1,522.0	29.3	60.6
7.6 - 8.5	38	58	73	157	7.8	8.6	297.5	504.3	19.3	20.1	750.1	2,026.3	48.6	80.7
6.6 - 7.5	63	37	137	193	6.1	6.3	387.6	232.2	25.1	9.2	1,137.7	2,258.5	73.7	90.0
5.6 - 5.6	57	33	193	227	4.2	4.3	237.5	141.9	15.4	5.6	1,375.2	2,400.4	89.1	95.6
4.6 - 5.5	45	25	238	252	2.6	2.8	116.6	70.6	7.5	2.8	1,491.8	2,471.1	99.6	98.5
3.6 - 4.5	25	18	263	270	1.6	1.8	40.7	33.2	2.6	1.3	1,532.6	2,504.3	99.3	99.8
2.6 - 3.5	12	7	275	277	.8	.8	9.6	5.3	.6	.2	1,542.1	2,509.6	99.9	100.0
1.6 - 2.5	3		278		.4		1.5		.1		1,543.6		100.0	
Total	278	277					1,543.6	2,509.6	100.0	100.0				
Average					5.5	9.1								

1/Rounded to whole numbers.

Table 23—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 8 at beginning and end of period—1968-73

D.b.h class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	-----	Number	----		-----	Cubic feet	----		- Percent -		-Cubic feet -		- - Percent- -	
13.6 - 14.5		3		3		38.8		129.3		5.1		129.3		5.1
12.6 - 13.5		8		12		29.9		249.5		9.9		378.8		15.0
11.6 - 12.5	3	12	3	23	21.9	24.3	73.1	284.1	4.9	11.3	73.1	662.8	4.9	26.3
10.6 - 11.5	8	22	12	45	17.1	19.5	142.1	422.8	9.5	16.8	215.3	1,085.7	14.4	43.1
9.6 - 10.5	13	20	25	65	13.7	14.6	182.4	291.9	12.2	11.6	397.7	1,377.6	26.5	54.7
8.6 - 9.5	20	32	45	97	10.8	11.5	216.1	363.5	14.4	14.4	613.7	1,741.1	41.0	69.2
7.6 - 8.5	33	47	78	143	7.9	8.8	263.2	409.6	17.6	16.3	877.0	2,150.7	58.5	85.4
6.6 - 7.5	58	27	137	170	5.8	6.0	338.8	160.9	22.6	6.4	1,215.8	2,311.6	81.2	91.8
5.6 - 6.5	40	32	177	202	4.1	4.0	163.1	128.1	10.9	5.1	1,378.9	2,439.7	92.0	96.9
4.6 - 5.5	32	22	208	223	2.5	2.2	79.6	48.0	5.3	1.9	1,458.5	2,487.7	97.4	98.8
3.6 - 4.5	13	17	222	240	1.3	1.3	17.0	20.9	1.1	.8	1,475.5	2,508.6	98.5	99.6
2.6 - 3.5	28	13	250	253	.8	.7	21.4	9.0	1.4	.4	1,496.9	2,517.6	99.9	100.0
1.6 - 2.5	5		255		.3		1.3		.1		1,498.2		100.0	
Total	255	253					1,498.2	2,517.6	100.0	100.0				
Average					5.9	9.9								

1/Rounded to whole numbers.

Table 24—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 9 (control) at beginning and end of period—1968-73

D.b.h class	Trees per acre 1/		Cumulative trees per acre		Volume per tree		Volume per acre				Cumulative volume per acre			
	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973	1968	1973
Inches	- - - - - Number- - - - -				- - - - - Cubic feet - - - -				- Percent -		- -Cubic feet - -		- Percent-	
14.6 - 15.5		2		2		42.7		71.1		2.0		71.1		2.0
13.6 - 14.5		0		2		0		0		0		71.1		2.0
12.6 - 13.5	2	3	2	5	26.6	27.9	44.3	93.1	1.9	2.6	44.3	164.2	1.9	4.6
11.6 - 12.5	2	3	3	8	21.0	22.3	35.0	74.5	1.5	2.1	79.3	238.7	3.4	6.7
10.6 - 11.5	4	17	7	25	17.2	19.1	67.3	317.7	2.4	8.9	136.6	556.4	5.8	15.6
9.6 - 10.5	12	32	18	57	13.2	15.3	154.3	485.4	6.6	13.6	291.0	1,041.9	12.4	29.3
8.6 - 9.5	30	45	48	102	10.3	11.9	308.9	535.5	13.1	15.1	599.9	1,577.4	25.5	44.4
7.6 - 8.5	45	72	93	173	7.9	8.7	357.3	620.6	15.2	17.4	957.2	2,198.0	40.7	61.8
6.6 - 7.5	78	67	172	240	5.6	6.1	437.5	405.9	18.6	11.4	1,394.7	2,603.9	59.2	73.2
5.6 - 6.5	92	73	264	313	3.8	4.3	344.4	313.1	14.6	8.8	1,739.2	2,916.9	73.9	82.0
4.6 - 5.5	95	100	358	413	2.4	2.6	230.2	263.5	9.8	7.4	1,969.3	3,180.4	83.6	89.4
3.6 - 4.5	133	107	492	520	1.4	1.5	189.4	163.2	8.0	4.6	2,158.7	3,343.7	91.7	94.0
2.6 - 3.5	163	165	655	685	.7	.7	110.9	122.7	4.7	3.4	2,269.6	3,466.3	96.4	97.5
1.6 - 2.5	342	325	997	1,010	.2	.3	84.6	90.4	3.6	2.5	2,354.2	3,556.7	100.0	100.0
Total	997	1,010					2,354.2	3,556.7	100.0	100.0				
Average					2.4	3.5								

1/Rounded to whole numbers.

Table 25—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 1 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
16.6 - 17.5	2	2	44.8	89.5	3.0	89.5	3.0
15.6 - 16.5	0	2	0	0	0	89.5	3.0
14.6 - 15.5	2	4	37.4	74.7	2.5	164.2	5.5
13.6 - 14.5	3	7	34.8	115.9	3.9	280.2	9.4
12.6 - 13.5	7	13	29.7	198.2	6.7	478.3	16.1
11.6 - 12.5	27	40	25.5	678.7	22.8	1,157.0	38.9
10.6 - 11.5	30	70	20.1	602.0	20.2	1,759.0	59.1
9.6 - 10.5	37	107	16.2	594.4	20.0	2,353.4	79.1
8.6 - 9.5	17	123	12.7	211.2	7.1	2,564.7	86.2
7.6 - 8.5	22	145	9.1	198.1	6.7	2,726.8	92.9
6.6 - 7.5	20	165	6.6	131.3	4.4	2,894.1	97.3
5.6 - 6.5	10	175	4.3	43.3	1.5	2,937.4	98.7
4.6 - 5.5	8	183	3.2	26.4	.9	2,963.8	99.6
3.6 - 4.5	5	188	1.8	9.2	.3	2,973.1	99.9
2.6 - 3.5	2	190	1.2	2.0	.1	2,975.0	100.0
Total	190			2,975.0	100.0		
Average			15.7				

1/Rounded to whole numbers.

Table 26—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 2 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
18.6 - 19.5	2	2	73.2	122.1	4.4	122.1	4.4
17.6 - 18.5	2	3	62.4	104.0	3.7	226.0	8.1
16.6 - 17.5	2	5	55.4	92.3	3.3	318.4	11.4
15.6 - 16.5	3	8	45.0	149.0	5.4	468.3	16.8
14.6 - 15.5	2	10	39.0	65.0	2.3	533.3	19.1
13.6 - 14.5	12	22	32.7	381.3	13.7	914.5	32.8
12.6 - 13.5	12	33	28.9	337.7	12.1	1,252.2	44.9
11.6 - 12.5	15	48	22.9	343.3	12.3	1,595.6	57.2
10.6 - 11.5	17	65	18.7	311.6	11.2	1,907.2	68.4
9.6 - 10.5	23	88	14.5	338.4	12.1	2,245.6	80.5
8.6 - 9.5	8	97	10.6	88.6	3.2	2,334.2	83.7
7.6 - 8.5	18	115	8.2	150.8	5.4	2,484.9	89.1
6.6 - 7.5	28	143	6.0	170.6	6.1	2,655.6	95.2
5.6 - 6.5	20	163	4.2	83.7	3.0	2,739.3	98.2
4.6 - 5.5	12	175	2.8	32.2	1.2	2,771.5	99.4
3.6 - 4.5	12	187	1.5	18.0	.6	2,789.5	100.0
Total	187			2,789.5	100.0		
Average			14.9				

1/Rounded to whole numbers.

Table 27—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 3 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
15.6 - 16.5	2	2	49.2	82.0	2.6	82.0	2.6
14.6 - 15.5	0	2	0	0	0	82.0	2.6
13.6 - 14.5	7	8	34.1	230.8	7.3	312.8	9.9
12.6 - 13.5	17	25	29.6	493.8	15.7	806.5	25.6
11.6 - 12.5	20	45	24.4	487.5	15.5	1,294.0	41.1
10.6 - 11.5	28	73	19.5	551.2	17.5	1,845.2	58.6
9.6 - 10.5	38	112	15.5	595.6	18.9	2,440.8	77.6
8.6 - 9.5	30	142	12.7	380.0	12.1	2,820.8	89.6
7.6 - 8.5	13	155	8.9	119.1	3.8	2,939.9	93.4
6.6 - 7.5	17	172	6.5	109.0	3.5	3,048.9	96.9
5.6 - 6.5	18	190	4.7	86.1	2.7	3,135.0	99.6
4.6 - 5.5	2	192	2.5	4.2	.1	3,139.2	99.8
3.6 - 4.5	3	195	1.7	5.5	.2	3,144.7	99.9
2.6 - 3.5	2	197	1.1	1.8	.1	3,146.5	100.0
Total	197			3,146.5	100.0		
Average			16.0				

1/Rounded to whole numbers.

Table 28—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 4 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
13.6 - 14.5	8	8	34.3	286.1	9.2	286.1	9.2
12.6 - 13.5	13	22	28.9	384.9	12.3	671.0	21.5
11.6 - 12.5	30	52	25.2	755.9	24.2	1,425.8	45.7
10.6 - 11.5	28	80	19.7	558.3	17.9	1,985.1	63.5
9.6 - 10.5	23	103	15.3	356.5	11.4	2,341.6	74.9
8.6 - 9.5	27	130	12.0	320.2	10.2	2,661.9	85.2
7.6 - 8.5	25	155	9.4	234.7	7.5	2,896.6	92.7
6.6 - 7.5	22	177	6.5	140.9	4.5	3,037.5	97.2
5.6 - 6.5	13	190	4.3	58.0	1.9	3,095.5	99.1
4.6 - 5.5	7	197	2.8	18.4	.6	3,113.9	99.6
3.6 - 4.5	7	203	1.6	10.9	.4	3,124.8	100.0
Total	203			3,124.8	100.0		
Average			15.4				

1/Rounded to whole numbers.

Table 29—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 5 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
17.6 - 18.5	2	2	60.3	100.5	3.0	100.5	3.0
16.6 - 17.5	0	2	0	0	0	100.5	3.0
15.6 - 16.5	3	5	53.7	179.1	5.3	279.6	8.3
14.6 - 15.5	7	12	41.8	279.0	8.3	558.5	16.6
13.6 - 14.5	12	23	35.5	414.6	12.3	973.1	28.9
12.6 - 13.5	13	37	30.1	401.7	11.9	1,374.8	40.9
11.6 - 12.5	12	48	24.6	286.9	8.5	1,661.7	49.4
10.6 - 11.5	23	72	19.2	448.4	13.3	2,110.1	62.7
9.6 - 10.5	23	95	16.2	377.7	11.2	2,487.8	74.0
8.6 - 9.5	28	123	11.8	335.6	10.0	2,823.4	83.9
7.6 - 8.5	13	137	9.5	126.3	3.8	2,949.7	87.7
6.6 - 7.5	28	165	6.5	185.2	5.5	3,134.9	93.2
5.6 - 6.5	32	197	4.6	146.3	4.4	3,281.2	97.5
4.6 - 5.5	25	222	2.8	69.3	2.1	3,350.5	99.6
3.6 - 4.5	5	227	1.3	6.4	.2	3,356.9	99.8
2.6 - 3.5	8	235	.8	7.0	.2	3,363.9	100.0
Total	235			3,363.9	100.0		
Average			14.3				

1/Rounded to whole numbers.

Table 30—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 6 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
15.6 - 16.5	3	3	48.2	160.8	4.9	160.8	4.9
14.6 - 15.5	3	7	42.1	140.3	4.3	301.1	9.2
13.6 - 14.5	2	8	35.5	59.2	1.8	360.3	11.0
12.6 - 13.5	5	13	28.1	140.6	4.3	500.9	15.3
11.6 - 12.5	27	40	23.9	637.2	19.4	1,138.1	34.7
10.6 - 11.5	28	68	18.6	525.8	16.0	1,663.9	50.7
9.6 - 10.5	30	98	15.4	462.7	14.1	2,126.6	64.8
8.6 - 9.5	32	130	11.8	372.9	11.4	2,499.4	76.1
7.6 - 8.5	33	163	8.6	285.4	8.7	2,784.8	84.8
6.6 - 7.5	40	203	6.5	261.0	8.0	3,045.8	92.8
5.6 - 6.5	32	235	4.4	140.1	4.3	3,185.9	97.0
4.6 - 5.5	27	262	2.9	76.5	2.3	3,262.5	99.4
3.6 - 4.5	12	273	1.7	19.3	.6	3,281.8	99.9
2.6 - 3.5	2	275	1.1	1.9	.1	3,287.7	100.0
Total	275			3,287.7	100.0		
Average			11.9				

1/Rounded to whole numbers.

Table 31—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 7 at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
14.6 - 15.5	5	5	43.4	217.1	6.0	217.1	6.0
13.6 - 14.5	10	15	36.0	359.8	9.9	576.9	15.9
12.6 - 13.5	7	22	30.0	200.0	5.5	776.9	21.4
11.6 - 12.5	18	40	25.6	468.7	12.9	1,245.6	34.3
10.6 - 11.5	22	62	20.5	445.2	12.3	1,690.8	46.6
9.6 - 10.5	45	107	16.3	732.2	20.2	2,423.0	66.8
8.6 - 9.5	48	155	12.8	617.2	17.0	3,040.2	83.8
7.6 - 8.5	33	188	9.2	308.2	8.5	3,348.4	92.3
6.6 - 7.5	25	213	6.6	166.1	4.6	3,514.6	96.8
5.6 - 6.5	12	225	4.4	51.0	1.4	3,565.6	98.3
4.6 - 5.5	17	242	2.9	48.5	1.3	3,614.1	99.6
3.6 - 4.5	7	248	2.0	13.1	.4	3,627.1	99.9
2.6 - 3.5	2	250	1.1	1.8	.1	3,628.9	100.0
Total	250			3,628.9	100.0		
Average			14.5				

1/Rounded to whole numbers.

Table 32—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 8 at end of period—1978

D.b.h. class	Trees per acre[1/]	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - - Number - - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
16.6 - 17.5	2	2	59.7	99.5	2.8	99.5	2.8
15.6 - 16.5	2	3	50.0	83.3	2.3	182.8	5.1
14.6 - 15.5	5	8	44.0	220.2	6.1	403.0	11.2
13.6 - 14.5	8	17	36.8	306.8	8.5	709.7	19.7
12.6 - 13.5	22	38	31.5	682.7	19.0	1,392.4	38.7
11.6 - 12.5	15	53	24.9	373.7	10.4	1,766.1	49.1
10.6 - 11.5	25	78	20.2	504.4	14.0	2,270.5	63.1
9.6 - 10.5	30	108	15.7	470.0	13.1	2,740.4	76.2
8.6 - 9.5	32	140	12.4	391.2	10.9	3,131.6	87.1
7.6 - 8.5	22	162	9.1	197.9	5.5	3,329.5	92.6
6.6 - 7.5	23	185	6.1	143.5	4.0	3,473.0	96.6
5.6 - 6.5	12	197	4.6	53.8	1.5	3,526.8	98.0
4.6 - 5.5	18	215	2.6	47.1	1.3	3,573.9	99.4
3.6 - 4.5	17	232	1.3	22.0	.6	3,595.9	100.0
2.6 - 3.5	2	233	.8	1.3	.0	3,597.2	100.0
Total	233			3,597.2	100.0		
Average			15.4				

[1/] Rounded to whole numbers.

Table 33—Stampede Creek: live trees per acre by d.b.h. class, volume per tree, volume per acre, and cumulative volume per acre, treatment 9 (control) at end of period—1978

D.b.h. class	Trees per acre 1/	Cumulative trees per acre	Volume per tree	Volume per acre		Cumulative volume per acre	
Inches	- - Number - -		Cubic feet	Cubic feet	Percent	Cubic feet	Percent
16.6 - 17.5	2	2	59.3	98.8	2.0	98.8	2.0
15.6 - 16.5	0	2	0	0	0	98.8	2.0
14.6 - 15.5	2	3	45.9	76.5	1.6	175.3	3.6
13.6 - 14.5	2	5	37.5	62.4	1.3	237.7	4.8
12.6 - 13.5	8	13	31.3	258.9	5.3	496.6	10.1
11.6 - 12.5	20	33	26.0	520.7	10.6	1,017.3	20.7
10.6 - 11.5	42	75	20.7	862.7	17.6	1,880.0	38.3
9.6 - 10.5	37	112	16.1	589.0	12.0	2,469.0	50.3
8.6 - 9.5	52	163	12.8	658.9	13.3	3,127.8	63.8
7.6 - 8.5	50	213	9.5	473.5	9.6	3,601.3	73.4
6.6 - 7.5	60	273	6.7	403.0	8.2	4,004.3	81.6
5.6 - 6.5	70	343	4.7	326.1	6.6	4,330.4	88.3
4.6 - 5.5	95	438	2.8	262.9	5.4	4,593.4	93.6
3.6 - 4.5	92	530	1.5	141.5	2.9	4,734.8	96.5
2.6 - 3.5	130	660	.8	101.5	2.1	4,836.3	98.6
1.6 - 2.5	227	887	.3	68.6	1.4	4,904.9	100.0
Total	887			4,904.9	100.0		
Average			5.5				

[1/] Rounded to whole numbers.

Study area	*Cooperator*
Skykomish	Western Forestry Research Department Weyerhaeuser Company Centralia, Washington
Hoskins	School of Forestry Oregon State University Corvallis, Oregon
Rocky Brook	USDA Forest Service Pacific Northwest Region and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Clemons	Western Forestry Research Department Weyerhaeuser Company Centralia, Washington
Francis	Washington State Department of Natural Resources Olympia, Washington
Iron Creek	USDA Forest Service Pacific Northwest Region and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Stampede Creek	USDA Forest Service Pacific Northwest Region and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Sayward Forest	Canadian Forestry Service Department of the Environment Victoria, British Columbia
Shawnigan Lake	Canadian Forestry Service Department of the Environment Victoria, British Columbia

Consultative services have been provided by the University of Washington, Seattle, and the Bureau of Land Management, U.S. Department of the Interior.

WILLIAMSON, RICHARD L.; CURTIS, ROBERT O. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 7—Preliminary results, Stampede Creek, and some comparisons with Iron Creek and Hoskins. Res. Pap. PNW-323. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 42 p.

Results of the Stampede Creek LOGS study in southwest Oregon are summarized, and results are compared with two more-advanced LOGS studies and, in general, are similar. To age 43, thinning in this low site III Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand resulted in some reduction in volume growth and moderate gains in diameter growth. Growth was strongly related to level of growing stock. Desirable density levels are recommended for young Douglas-fir stands.

KEYWORDS: Growing stock (-increment/yield, increment -) growing stock management, stand density, thinnings, Douglas-fir, *Pseudotsuga menziesii*, southwest Oregon, Oregon (southwest), series—Douglas-fir LOGS.

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Development of Young Growth Western Redcedar Stands

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Abstract

Nystrom, Michael N.; DeBell, Dean S.; Oliver, Chadwick D. Development of young-growth western redcedar stands. Res. Pap. PNW-324. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 9 p.

Historical development of western redcedar *(Thuja plicata Donn)* trees and stands, 46 to 58 years old, was analyzed on four upland sites in western Washington.

Keywords: Stand density, silviculture, increment, yield (forest), young-growth stands, western redcedar, *Thuja plicata.*

Summary

Historical development of western redcedar *(Thuja plicata* Donn) stands, 46 to 58 years old, was analyzed on four upland sites in western Washington. Differentiation in height growth occurred at an early age; at age 5, eventual dominants were taller than eventual intermediates. Diameter and volume growth of individual trees were negatively correlated with number of stems per acre. Volume production in these unmanaged, natural stands was comparable to estimated volumes for fully stocked natural stands of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) on these sites but was less than estimated volumes for western hemlock *(Tsuga heterophylla* (Raf.) Sarg.). Merchantable yields of western redcedar should be higher in plantations or natural stands with early stocking control. The potential for future management of this species appears excellent.

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Introduction

Western redcedar (*Thuja plicata* Donn) is an important commercial species in old-growth forests of the northwestern United States and Canada. Because the heartwood is workable and durable, redcedar has been utilized for a variety of products and is particularly valuable for exterior uses. In Oregon and Washington, current harvest of redcedar is more than double the annual growth rate (Bolsinger 1979). Value of old-growth cedar has increased to the point that theft of trees and logs is a serious problem. Although cedar products have been produced primarily from old growth, many products are being made from young growth. Values of young-growth cedar logs have increased; in some cases, prices for young-growth redcedar logs have surpassed prices for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Despite such changes in value and the depletion of the old-growth resource, few attempts have been made in the Pacific Northwest to establish plantations or to manage young-growth natural stands of western redcedar. Operational planting has been confined mainly to sites either too wet or too infested with laminated root rot (*Phellinus weirii*) for successful establishment of other conifer species.

There are several reasons for the limited attention devoted to regeneration and management of western redcedar. One is the prevailing opinion that less wood can be produced in young-growth western redcedar stands than can be grown with Douglas-fir or western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). It is also commonly assumed that young-growth redcedar trees will be too fluted, tapered, and limby to make quality wood products. Thus, management of redcedar is intuitively regarded as less profitable (Bolsinger 1979). Research information and operational experience pertaining to stand development, yield potential, and management of young-growth western redcedar are scant. To help fill this void, we studied the present characteristics and analyzed the historical development of four, relatively pure western redcedar stands, aged 46 to 58 years.

Methods

Study Areas

Pure stands of second-growth western redcedar rarely developed after the old-growth coniferous forests in western Washington were logged. We did, however, find four nearly pure, young-growth redcedar stands of 1 to 5 acres each in the foothills of the Cascade Range. Two stands (areas A and B) were at an elevation of 850 feet on the Gordon C. Marckworth Forest (State of Washington Department of Natural Resources) and two (areas C and D) were at an elevation of 1,100 feet on the Pilchuck Tree Farm (Pacific Denkmann Company) (fig. 1). Old-growth stands in both areas had been logged about 1920, and patches of relatively pure redcedar became established naturally. Annual precipitation averages 45 to 60 inches, most occurring as rain during winter. The soil of area A was an Everett gravelly sandy loam (Dystric Xerochrepts); area B contained an Indianola loamy sand (Dystric Xeropsamments); areas C and D were on Cathcart loam (Andic Xerochrepts). These soils were moderately well drained to well drained, and the areas were more representative of Douglas-fir sites than of the moist to wet sites on which stands containing a large component of redcedar are commonly assumed to grow. Site indices for western redcedar (Kurucz 1978) ranged from 78 to 99 feet. Site indices for other conifers as determined by trees scattered in and around the areas ranged from 106 to 123 feet for Douglas-fir (King 1966) and from 90 to 111 feet for western hemlock (Wiley 1978). Understory vegetation was minimal, and it consisted primarily of vine maple (*Acer circinatum* Pursh), salal (*Gaultheria shallon* Pursh), huckleberry (*Vaccinium* spp.), and occasionally, swordfern (*Polystichum munitum* (Kaulf.) Presl.).

Figure 1.—Location of second-growth western redcedar stands used in study in western Washington

Sampling Procedures

For information on the average and range in stand characteristics, four rectangular 1/20-acre plots were delineated in each of areas A, B, and C; only two plots were established in area D because this stand was very small. Diameter, height, crown class, taper, and fluting were recorded for each tree on all 14 plots. Cubic-foot (total stem) volumes were estimated from the comprehensive tree volume and tarif tables of Turnbull and others (1972).

Within each plot, three subsampling units of variable size were selected for more intensive study. Each unit was centered around a dominant redcedar tree and was defined by a line drawn midway between the canopy projections of the central dominant cedars and surrounding dominant cedars (Oliver 1978). One redcedar tree in each crown class present in each subsampling unit was measured for total height, diameter, and basal age (increment cores extracted at 1 foot). Thus, specific tree information was gathered on 160 trees—14 plots, three subsampling units per plot, and 3 or 4 trees per subsampling unit.

Two subsampling units in each of the four areas were used for a detailed reconstruction analysis (Henry and Swan 1974; Oliver 1978, 1982). These units were representative of the number, age, and size of dominant trees observed in the overall inventory, and they contained a typical sample of trees of other crown classes in each stand. Searches were conducted on each unit to identify minimum past mortality and to reveal past disturbance (fire, for example) by removing litter (Oliver and Stephens 1977). Then, one tree in each crown class was felled and disks were cut at 0.5 foot, 4.5 feet, and at 4-foot intervals thereafter. Ring counts and radial measurements taken on these disks were used to determine height, diameter, and volume of the trees at previous times.

Development of the stands and interactions among trees were reconstructed by examining past patterns of height and diameter growth of trees in each crown class. The age at which significant differentiation first occurred was determined by comparing heights and diameters of trees of various crown classes on each subsampling unit at past ages by paired t-tests (Oliver 1978, Wierman and Oliver 1979). Linear regressions were used to ascertain relationships between diameter growth and stand density.

Patterns of volume growth were developed by using the height- and diameter-age data to compute cubic-foot volumes by 5-year intervals with the TREVOL computer program.[1/] From this information, cumulative and periodic cubic-foot volume growth curves were constructed for individual trees. Past plot volumes for each of the four areas were estimated by assuming that volume growth of present trees in each crown class followed the average pattern displayed in that area by the stem-analyzed trees of the same crown class. Thus, the percentage (fraction) of final volume attained in each preceding 5-year period by sampled trees of each crown class was multiplied by the present total area volumes for each crown class, and the products were summed by period. This procedure underestimates past volumes of lower crown classes by amounts equivalent to mortality losses.

[1/] Rustagi, Krishna P. 1975. TREVOL computer program. Personal communication. Dr. Rustagi is Associate Professor of Forest Management, College of Forest Resources, University of Washington, Seattle.

Present Stand Characteristics

Representative views of the young-growth redcedar are shown on the cover and in figure 2. Although fluted boles are considered common in red cedar trees grown in the open, in sparsely stocked stands, and in many mixed stands, little fluting was noted these fully stocked, nearly pure weste redcedar stands. Eighty-one percent the trees were essentially round in cross section at the root collar; anoth 18 percent were slightly fluted at the base but round at breast height. Thus 99 percent of the trees were of norma shape at breast height.

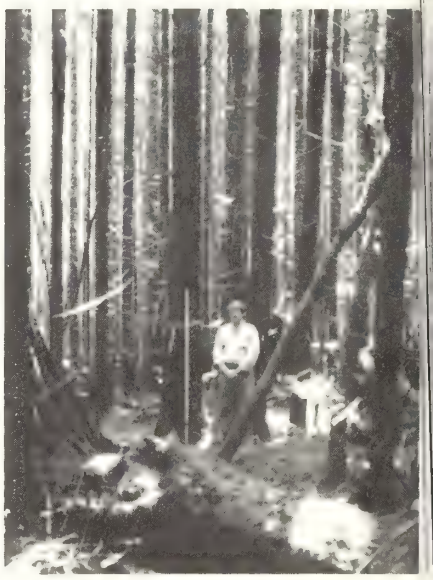

Figure 2.—48-year-old second-growth, natural western redcedar stand on well-drained soils in the Marckworth Forest, Washington. When redcedar grows in pure, even-aged stands it produces small-limbed, untapered unfluted stems and per-acre volumes comparable to natural Douglas-fir.

Other data for each area are given in tables 1 and 2. Stand ages (age of oldest redcedar) ranged from 46 to 58 years. Basal area for the redcedar component of each stand averaged about 260 square feet per acre, ranged from 240 to 290 square feet, and always equaled at least three-fourths of the total basal area. Site index for redcedar (Kurucz 1978) ranged from 78 to 99 feet and redcedar stocking, from 580 to 990 stems per acre; thus, redcedar volumes also varied considerably—6,730 to 8,900 cubic feet per acre.

Stands in all four areas were differentiated into distinct crown classes. Data on specific attributes of each crown class (table 2) provide additional understanding of stand structure in the four areas. Ages of trees in the dominant, codominant, and intermediate crown classes were similar; thus, differentiation among these classes does not appear to be related to time of establishment. The suppressed crown class did include younger trees, however. On the average, 22 percent of the total redcedar stems were dominants, 21 percent were codominants, 28 percent were intermediates, and 29 percent were suppressed. Stand A was the youngest, least dense stand, and it differed most from the above-mentioned average structure. The major differences were a greater proportion of codominant trees (29 percent) and far fewer suppressed trees (15 percent).

Historical Composition of Stands

Numbers and species of trees in the study areas since establishment of the stands were estimated by litter searches on portions of the area. In addition to western redcedar, the selected subsampling units contained evidence of western hemlock, bitter cherry *(Prunus emarginata* Dougl.), and willow *(Salix* spp.). The hardwood species apparently were dominant features of the early stages of vegetation in all areas and in most subsampling units. Much mortality had occurred over the years: more than one-half of all redcedar stems had died; all of the bitter cherry in the litter-searched areas had succumbed and, with one exception, so had the willow. Hemlock had been and still was a significant component in two subsampling units.

Table 1—Site index, age, density, and yield characteristics of young-growth western redcedar stands in 4 study areas in western Washington

Characteristic	Unit of measure	Marckworth Forest		Pilchuck Tree Farm	
		Area A	Area B	Area C	Area D
Site index at breast-high age 50:					
Western redcedar	Feet	99	83	78	82
Douglas-fir	Feet	118	123	106	106
Western hemlock	Feet	111	104	92	90
Stand age 1/	Years	46	48	58	48
Stems per acre:					
Western redcedar	Number	580	840	710	990
All species	Number	730	1,000	820	1,300
Basal area per acre:					
Western redcedar	Square feet	260	240	290	240
All species	Square feet	320	260	310	320
Cubic volume per acre:					
Western redcedar	Cubic feet	8,900	6,830	8,890	6,730
All species	Cubic feet	10,680	7,090	8,900	7,670
Mean annual volume increment:					
Western redcedar	Cubic feet	193	142	153	140
All species	Cubic feet	232	148	153	160

1/ Age of oldest western redcedar tree.

Table 2—Tree size, age, density, and yield characteristics by crown class of western redcedar in 4 study areas in western Washington

Crown class and characteristic	Unit of measure	Marckworth Forest		Pilchuck Tree Farm	
		Area A	Area B	Area C	Area D
Dominant redcedar:					
Total height	Feet	86.7	75.0	82.8	73.6
Average diameter	Inches	12.7	11.6	14.9	12.1
Stems	Number	150	200	140	180
Cubic volume	Cubic feet	4,680	4,520	5,230	4,340
Age range	Years	43-50	42-48	52-59	41-49
Codominant redcedar:					
Total height	Feet	77.9	68.2	71.2	65.3
Average diameter	Inches	9.2	7.5	9.2	6.7
Stems	Number	170	160	140	160
Cubic volume	Cubic feet	2,640	1,410	1,870	1,110
Age range	Years	43-49	31-48	48-59	41-46
Intermediate redcedar:					
Total height	Feet	69.3	51.3	57.7	58.2
Average diameter	Inches	6.7	5.3	6.5	4.9
Stems	Number	180	200	170	320
Cubic volume	Cubic feet	1,360	780	1,115	980
Age range	Years	42-48	40-47	40-60	41-46
Suppressed redcedar:					
Total height	Feet	48.2	26.4	30.2	26.3
Average diameter	Inches	4.3	2.6	3.0	3.1
Stems	Number	85	275	260	330
Cubic volume	Cubic feet	220	180	260	310
Age range	Years	35-47	32-45	24-56	21-32

The following species were observed in the stands but did not occur on the litter-searched plots. Douglas-fir was common and was dominant where present. Pacific yew *(Taxus brevifolia* Nutt.) occurred as a scattered understory tree with little apparent impact on stand development. Vine maple and red alder *(Alnus rubra* Bong.) were fairly common and may have been important factors in early development and spatial arrangement of stems within the stands.

Height Growth and Differentiation

Average heights of dominant redcedar trees on the four study areas ranged from 73.6 to 86.7 feet. When differences in tree ages are considered, this represents a range of 1.6 to 1.9 feet in mean annual height increment. Trees in lower crown classes were correspondingly shorter and lower in height increment. General patterns of cumulative and periodic height growth of three crown classes are illustrated in figure 3 In general, height growth of all crown classes was relatively slow during the first 5 years; it peaked during the second decade. Thereafter, growth of dominant trees declined slightly to 1.6 feet per year and codominant trees to 1.4 feet; growth has since remained stable. Height growth of intermediate trees, however, has continued to decline. The pattern of growth for suppressed trees is not shown because many rings in the lower bole were missing; thus, curves of height growth to age relationships developed from suppressed tree data would not be accurate. Jackson and Knapp (1914) reported that height growth of redcedar was most rapid between the ages of 10 and 30 years in a thrifty, 80-year-old pure stand and also in a 200-year-old "somewhat suppressed" stand. Although they did not report height-growth patterns by individual crown classes, the trees they examined and those in our study appeared to follow similar height-growth patterns.

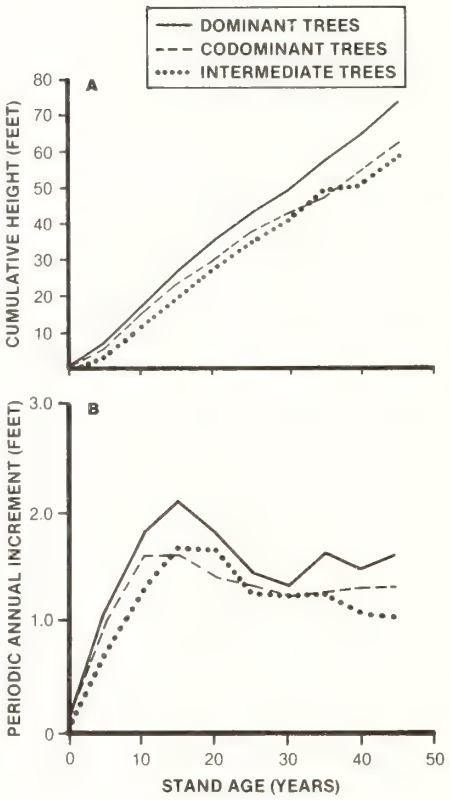

Figure 3.—Average cumulative height and periodic annual height growth patterns for western redcedar trees, by crown class.

There is one important exception to these general statements about height-growth patterns. Cumulative and periodic growth trends for individual trees on all study areas suggest a significant growth depression after the severe freeze of mid-November 1955. This depression is masked in figure 3 because data are averaged by stand age rather than by calendar year. The freeze affected growth patterns of many species in western Washington (Duffield 1956). Evidence of the freeze in redcedar includes crooked stems at the point of the freeze, compartmentalized rot in tips of trees below this point, dead spike tops at crooks that are well below the present terminal, and gaps in age below and above the crooks.

Terminal leaders and portions of the upper stems of many trees apparently were killed by the freeze, and lower branches assumed dominance. As much as 8 feet in attained height of some western redcedar trees may have been lost by the freeze.

Paired t-statistic values showed that eventual intermediate trees were already significantly shorter than dominants by stand age 5; dominants and codominants, however, were not consistently different statistically until after age 25. The long time needed to establish the significance of dominance among taller trees in these stands may be partially caused by the 1955 freeze and changes in crown class associated with it. Nevertheless, these findings suggest that trees to cut or favor in precommercial thinning could be identified with reasonable confidence in pure western redcedar stands between ages 5 and 10 years.

Diameter Growth

General patterns of cumulative and periodic diameter growth are illustrated in figure 4. Diameter increment of all crown classes appeared to peak at about age 15. Growth of dominants has remained fairly stable since age 20, averaging about 0.25 inch per year. Diameter growth of codominant trees declined from age 15 through age 30 and since has averaged about 0.14 inch per year. Growth of intermediate trees has continued to decline. Diameter growth performance of the thrifty young-growth cedar stand studied by Jackson and Knapp (1914) peaked somewhat later (age 25) but averaged about 0.25 inch per year through age 70.

Paired t-statistics showed that diameters of eventual dominant and intermediate trees differed significantly by age 5. Diameters of dominants and codominants, however, were not significantly different during the first 40 years. As with height differentiation, it seems likely that the 1955 freeze and changes associated with it have overshadowed normal trends in diameter differentiation between these two crown classes.

Diameter growth was influenced by stand density. Diameter of dominant trees at age 40 was negatively related to the total number of stems in the past ($r=-0.76$) and to the present number of dominant trees per acre ($r=-0.76$). Such relationships in natural redcedar stands suggest that this species will respond well to wide initial spacing or to early control of density. Best diameter growth of individual trees will occur at density levels considerably lower than those encountered in these natural stands.

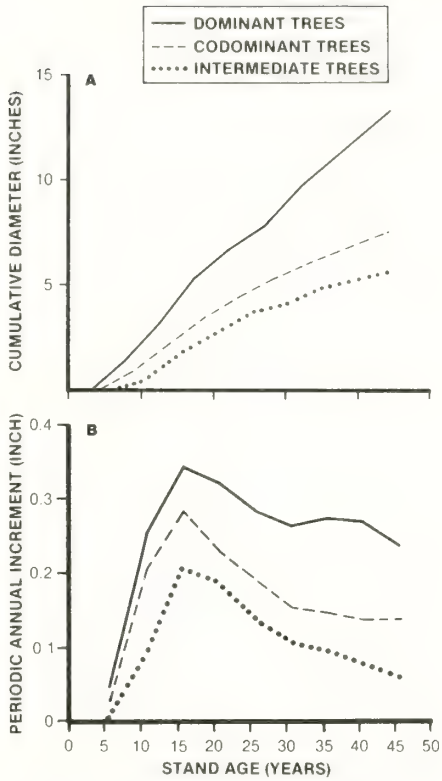

Figure 4.—Average cumulative diameter and periodic annual diameter growth patterns for western redcedar trees, by crown class.

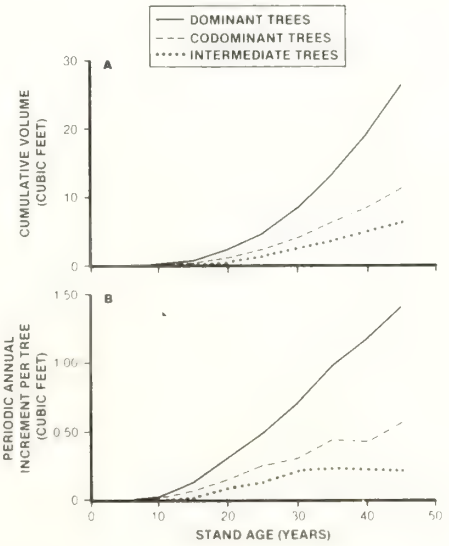

Figure 5.—Mean cumulative volume growth and periodic annual volume growth patterns for western redcedar trees, by crown class.

Volume Growth (Individual Trees)

Cumulative volume and periodic annual volume growth are illustrated by crown class in figure 5. Volume growth rates of all dominant redcedars examined by stem analysis were still accelerating in the fifth decade after establishment. Volume growth of codominant trees was less than that of dominant trees, but it was also still increasing. Intermediate trees attained their volume growth peak at about age 30 and have since grown at a relatively constant rate.

Stand density also had a strong effect on volume production of dominant trees. Volume at age 40 was negatively correlated with both the total number of stems in the past ($r=-0.76$) and the present number of dominant stems ($r=-0.70$) per acre. Growth of individual trees was greatest at the lowest densities examined, but maximum stand volume production may be attained at higher densities. Tree taper, limbiness, and stem fluting are also likely to increase if spacing becomes too wide.

Volume Growth (Stand)

Table 3 contains estimates of average cumulative volume per acre for the redcedar components of the four study areas. Past volumes, reconstructed by methods described previously, do not include volume produced on trees that died before this study and thus underestimate past cumulative volumes, especially at younger ages. They also exclude volume of other species that occupied growing space in these stands. On the other hand, estimated yields from small plots tend to be higher than yields attainable over larger forest areas (Curtis 1983). British yield tables (Hamilton and Christie 1971) for western redcedar plantations indicate stand volumes after thinning which are comparable to our estimates for sites with similar top heights at 50 years. The data in table 3 provide a reasonable first approximation, and the potential volume production of western redcedar stands appears promising.

Table 3—Estimated average cumulative volume of western redcedar trees in 4 study areas in western Washington

Stand age	Marckworth Forest		Pilchuck Tree Farm	
	Area A	Area B	Area C	Area D
Years	Cubic feet per acre			
0	0	0	0	0
5	12	10	6	3
10	117	98	53	49
15	471	339	204	240
20	1,085	796	509	681
25	2,075	1,363	1,064	1,304
30	3,185	2,154	1,851	2,110
35	4,659	3,285	2,781	3,815
40	6,247	4,817	3,681	4,488
45	7,886	5,806	4,815	6,053
50	8,900	6,830	6,080	6,730
55			7,565	
60			8,890	

Volume growth trends for redcedar on these small plots are compared with fully stocked Douglas-fir and western hemlock stands for areas A and C, the highest and lowest quality sites studied (fig. 6). Volume estimates for Douglas-fir and hemlock are taken from McArdle and others (1961) and Barnes (1962) after the site index data in table 1 are converted to a 100-year base. Yield of normal western hemlock stands is substantially higher than yield of either western redcedar or Douglas-fir. Early growth of Douglas-fir is more rapid than that of redcedar, but volume production of these two species on 40- to 60-year rotations appears similar. Redcedar's reputation for slow growth compared with growth of Douglas-fir may result from many redcedar trees' having spent much of their early life in subdominant positions. In most natural stands of mixed species that contain western redcedar, the dominant trees are other conifers or red alder; most of these species have faster early growth than redcedar and, except for alder, are long lived. In the areas we studied, the early dominants were primarily short-lived hardwood species such as willows and bitter cherry. In an even-aged plantation with other vegetation controlled, early growth and volume production of western redcedar may be greater than that measured in this study. Comparisons of western redcedar and Douglas-fir in British plantations (Aldous and Low 1974) showed that western redcedar initially grew slower on almost all sites and performed poorly on harsh, exposed upland sites. Generally, however, redcedar became increasingly more productive than Douglas-fir as site class increased; that is, the better the site, the greater the superiority of western redcedar. Of 70 installations on which the two species were compared, cedar outperformed Douglas-fir at 14 installations and was equal to it at 2 installations.

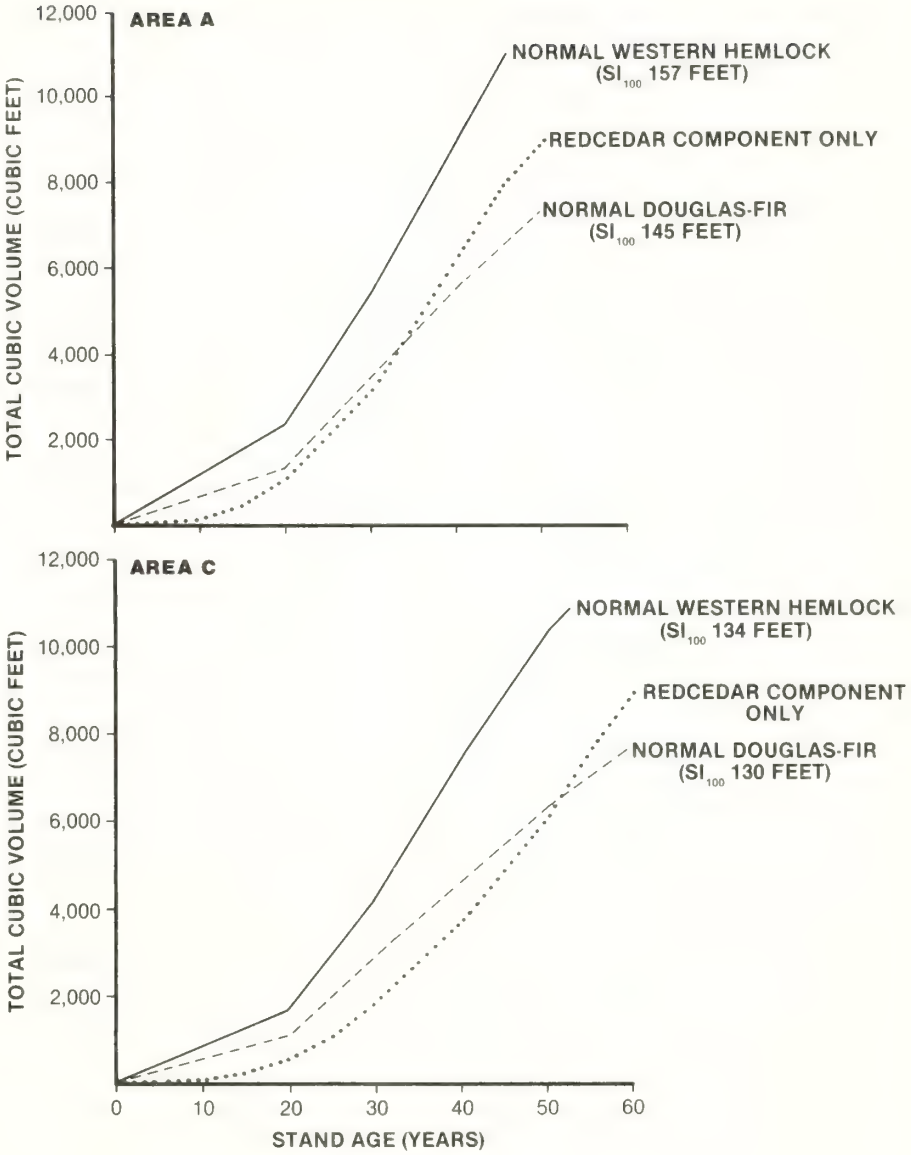

Figure 6.—Comparison of cumulative volume production of western redcedar; estimated normal yields of Douglas-fir and western hemlock.

Conclusions and Management Implications

Our study suggests that young-growth western redcedar has substantial management potential in moist portions of the Douglas-fir region:

1. Productive western redcedar stands can be grown on mesic, well-drained upland sites. Plantings of the species need not be limited to specialty uses as on wet areas or sites infested with root-rot fungi where other conifers are unlikely to produce adequate stands.

2. Diameter and volume growth of individual trees were negatively related to stocking levels. In well-spaced plantations or precommercially thinned natural stands, growth may be higher than that reported here.

3. Stand differentiation began at an early age. By year 5, eventual dominants were significantly larger in both height and diameter than eventual intermediates. Significant differences in height between eventual dominants and codominants did not occur until age 25, but damaging effects of a severe freeze in 1955 may have disrupted normal differentiation patterns. Trees to cut or favor in precommercial thinning could be selected with reasonable confidence by age 10 (or when tallest trees in the stand are about 15 feet tall).

4. Estimated yields of pure western redcedar stands on 40- to 60-year rotations appear at least comparable to "normal" yields for Douglas-fir but less than "normal" yields for western hemlock on the sites we studied. Site index (age 50) was less for redcedar than for the other species, but redcedar stands had more basal area than did Douglas-fir stands.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 acre = 0.4047 hectare
1 tree/acre = 2.471 trees/hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.06997 cubic meter/hectare

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Historical development of western redcedar *(Thuja plicata Donn)* trees and stands, 46 to 58 years old, was analyzed on four upland sites in western Washington.

Keywords: Stand density, silviculture, increment, yield (forest), young-growth stands, western redcedar, *Thuja plicata.*

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PNW-325

September 1984

Growth and Yield of Sitka Spruce and Western Hemlock at Cascade Head Experimental Forest, Oregon

Stephen H. Smith, John F. Bell, Francis R. Herman, and Thomas See

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Abstract

Smith, Stephen H.; Bell, John F.; Herman, Francis R.; See, Thomas. Growth and yield of Sitka spruce and western hemlock at Cascade Head Experimental Forest, Oregon. Res. Pap. PNW-325. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 30 p.

A study established in 83-year-old, even-aged stands of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) at Cascade Head Experimental Forest in the Siuslaw National Forest on the Oregon coast traces their development for 33 years. Statistical data collected from 12 permanent sample plots during four periods of growth illustrate the tremendous productive capacity of the Sitka spruce-western hemlock type.

Keywords: Increment (volume), stand volume, increment (basal area), increment (height), even-aged stands, Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*.

Summary

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) are the principal components of the Pacific Northwest coastal fog belt type (Meyer 1937) or the *Picea sitchensis* zone (Franklin and Dyrness 1973) found along the Oregon and Washington coasts. The tremendous potential for rapid growth and high yield of the Sitka spruce-western hemlock type ranks it among the most productive coniferous types in the world.

This report summarizes 33 years of data on growth and yield of mixed stands of Sitka spruce and western hemlock at Cascade Head Experimental Forest in the Siuslaw National Forest on the Oregon coast. Data were collected from 16 permanent sample plots established in the spring of 1935; 12 of the plots were in thrifty, well-stocked, 83-year-old, even-aged stands of Sitka spruce and western hemlock. The 12 plots were periodically remeasured to obtain detailed information about the silvical and growth characteristics of the type during four periods spanning 33 years; the study was concluded in 1968.

This report describes the study, summarizes data obtained from the permanent sample plots, and discusses results. Our primary purpose in presenting these data is to further define the extraordinary productivity of the Sitka-spruce-western hemlock coastal forest. This information on growth and yield focuses on cause-and-effect relationships rather than on indepth statistical analyses of the data.

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Introduction

The Study Area

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) permanent growth plots are located in the Cascade Head Experimental Forest, Siuslaw National Forest, near Otis on the Oregon coast (fig. 1). The 130-year-old forest supports a well-stocked stand of Sitka spruce and western hemlock, believed to have become established after the 350,000-acre (141 640-ha) Nestucca fire in 1845. The local climate is typical of the coastal fog belt with heavy precipitation, high humidity, frequent fog, and a minimum of temperature extremes (Franklin and Dyrness 1973). The Pacific Ocean influences the mild climate, providing a long growing season and favorable moisture conditions, even in the summer when frequent fog and clouds compensate for otherwise drier conditions (table 1).

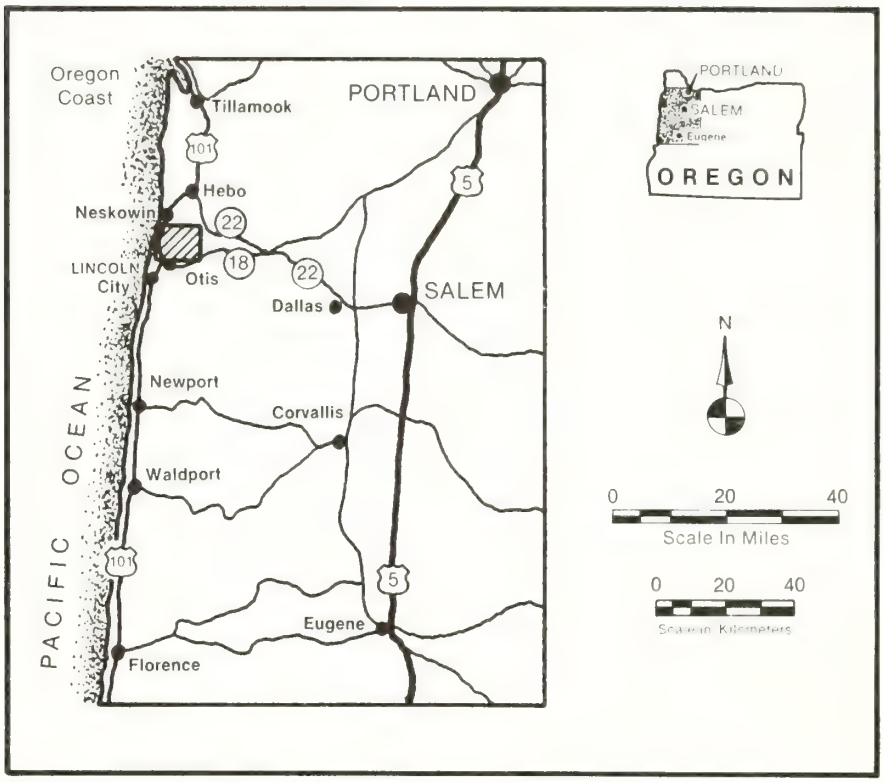


Figure 1.—Location of Cascade Head Experimental Forest.

Table 1—Comparison of climatic data for Cascade Head Experimental Forest (Otis, Oregon) with representative stations throughout the Pacific Northwest

Station	Elevation	Average air temperature					Precipitation	
		Annual	January	January minimum	July	July maximum	Average annual	June-August
	Feet (Meters)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	Inches (Centimeters)	Inches (Centimeters)
Otis, Oregon	161 (49.1)	50.5 (10.3)	41.5 (5.3)	36.0 (2.2)	59.5 (15.3)	69.6 (20.3)	98.3 (250)	6.4 (16)
Corvallis, Oregon	203 (61.9)	52.3 (11.3)	39.2 (4.0)	33.1 (.6)	66.0 (18.9)	80.8 (27.1)	39.5 (100)	1.9 (5)
Medford, Oregon	1,312 (399.9)	54.0 (12.2)	37.4 (3.0)	29.8 (-1.2)	72.1 (22.3)	89.2 (31.8)	19.6 (50)	1.4 (4)
Portland, Oregon	29 (8.8)	54.7 (12.6)	40.3 (4.6)	34.5 (1.4)	68.5 (20.3)	78.4 (25.8)	42.4 (108)	2.8 (7)
Seattle, Washington	111 (33.8)	52.9 (11.6)	40.1 (4.5)	34.0 (1.1)	65.7 (18.7)	75.4 (24.1)	35.0 (89)	3.1 (8)

Source: Franklin and Dyrness (1973).

Methods

In the spring of 1935, 16 permanent sample plots were established in even-aged stands of Sitka spruce and western hemlock, having an average age of 83 years.[1] Twelve 1-acre (0.405-ha) plots (fig. 2) varied in composition from nearly pure spruce to pure hemlock. The remaining plots were established in younger stands containing substantial amounts of red alder (*Alnus rubra* Bong.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). For each plot, boundaries were established, boundary trees blazed, and corner posts set and numbered. Plot trees were tagged with aluminum tags 4.5 feet (1.37 m) above seedling origin.[2] Heights of 10 to 40 trees per acre (24.7 to 98.8/ha) were measured to the nearest foot (30.5 cm). Diameters at breast height were measured to the nearest 0.1 inch (0.254 cm). Age counts were made on increment cores from 10 to 15 trees per plot. The plots were remeasured in 1940, 1945, 1955, and 1968 for the growth periods of 1935-40, 1941-45, 1946-55, and 1956-68. Of the 12 original spruce and hemlock plots, only 9 exist today; plot 2 was lost to roadbuilding; plot 6 to the 1962 Columbus Day windstorm; and plot 9 to logging activities. Initially, volume-diameter-height relationships were developed from tarif access equations for trees with height measurements (total height was measured on only a portion of the trees on a plot). Procedures for processing tarif access numbers by computer were adopted by use of British Columbia volume equation coefficients for immature coastal western hemlock, Sitka spruce, and Douglas-fir (Brackett 1973). Tarif access numbers for individual sample trees were calculated and tabulated by species, plot, and measurement year. Because of the high variation in the number of trees and the large range of diameter classes on individual plots, tarif access numbers were averaged and adjusted for each measurement year by species to determine an overall "average" tarif number (tables 2 and 3). This procedure provided a more adequate representation of tree diameters over the range of diameter classes; it also removed inconsistencies caused by the variation in the number of sample trees selected per plot and in height measurements between measurement years. The resulting adjusted access numbers were used in conjunction with the collected data on tree diameters to obtain individual estimates of volume for each tree. These estimates of volume, as well as other individual tree measurements, were tabulated and summarized by species, plot, and measurement year; they represent the basic statistical data presented in this report.

[1] Meyer, W. H. 1935. First report on sixteen permanent sample plots located on the Cascade Head Experimental Forest. 37 p. On file at Forestry Sciences Laboratory (Jerry F. Franklin), Corvallis, Oregon.

[2] At 4½ feet (1.37 m) above seedling origin, breast height was as much as 10 feet (3.05 m) above ground level for trees that began growth on rotted logs or stumps.

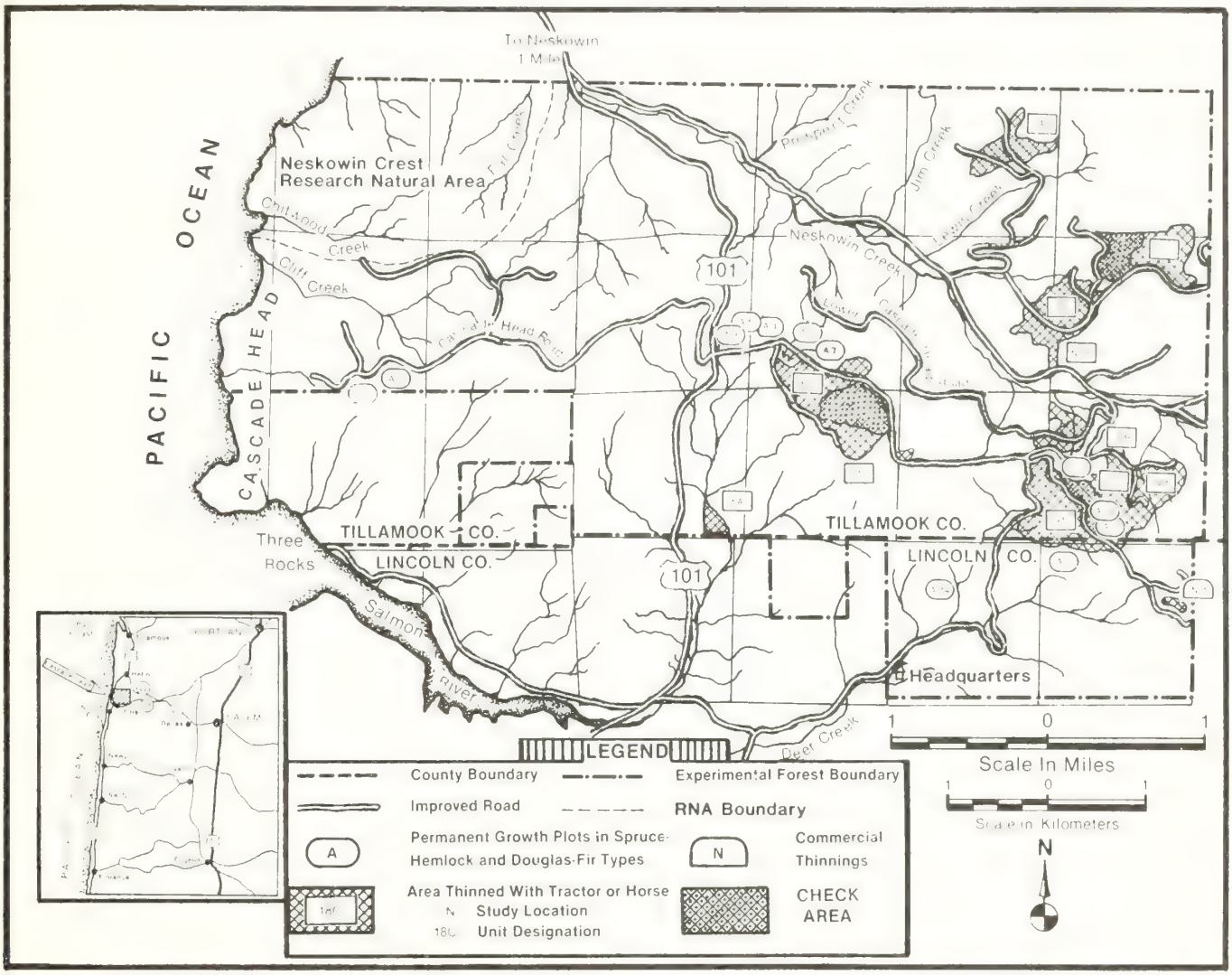


Figure 2.—Location of the 12 plots periodically remeasured, Cascade Head Experimental Forest

Table 2—Average tarif number for Sitka spruce by 1-acre (0.405-ha) plot and measurement year[1]

Plot	1935, age 83		1940, age 89		1945, age 94		1955, age 104		1968, age 116	
	Average tarif number	Number of height trees	Average tarif number	Number of height trees	Average tarif number	Number of height trees	Average tarif number	Number of height trees	Average tarif number	Number of height trees
1	--	0	45.3	4	--	0	48.9	3	49.9	3
3	53.3	23	55.1	15	55.4	33	57.1	22	59.5	11
4	46.4	20	49.0	33	47.6	28	49.4	30	51.7	24
5	48.7	27	53.0	32	52.8	31	53.9	32	56.6	30
6	44.6	8	46.2	10	47.4	9	51.0	12	--	--
7	46.8	13	49.5	9	53.0	10	50.3	12	53.5	11
8	46.6	1	--	0	--	0	48.5	2	46.0	3
9	40.7	24	41.7	46	--	--	--	--	--	--
10	38.8	22	41.1	22	41.5	22	44.2	25	47.4	26
12	47.7	10	49.1	10	51.2	9	50.5	12	54.0	9
13	48.5	8	50.8	9	51.6	9	53.7	8	56.2	10
Mean[2]	45.9	17.3	49.4	14.9	50.4	15.8	51.0	16.2	53.2	14.1

[1] Tarif number is the total cubic-foot (cubic-meter) volume from the stump to a 4-inch (10.2-cm) top for a tree of 1.0 square foot (0.0929 m^2) basal area at d.b.h. (Chambers and Foltz 1980). Height trees are used for determining average tarif numbers.

[2] Weighted average, weighted by number of height trees per plot.

Table 3—Average tarif number for western hemlock by 1-acre (0.405-ha) plot and measurement year[1]

Plot	1935, age 83		1940, age 89		1945, age 94		1955, age 104		1968, age 116	
	Average tarif number	Number of height trees	Average tarif number	Number of height trees	Average tarif number	Number of height trees	Average tarif number	Number of height trees	Average tarif number	Number of height trees
1	49.6	39	51.3	42	52.1	41	53.2	37	54.9	53
3	53.1	19	54.0	17	53.8	21	54.7	26	59.3	19
4	42.7	19	44.0	10	42.9	11	45.5	16	47.9	15
5	48.8	9	50.6	10	49.8	10	50.2	10	51.3	12
6	50.2	23	50.6	31	48.8	29	53.4	30	--	--
7	49.1	24	49.4	29	52.6	30	50.3	27	52.5	28
8	46.6	31	47.8	44	49.3	41	48.8	34	49.1	32
9	--	0	--	0	--	0	--	--	--	--
10	38.4	17	41.0	21	40.2	23	45.3	26	48.1	20
11	51.7	30	52.5	33	54.2	24	53.7	28	57.1	33
12	53.4	28	53.3	35	54.3	30	55.6	28	57.6	31
Mean[2]	48.7	17.3	49.9	26.8	50.6	25.7	51.2	25.8	53.7	27.0

[1] Tarif number is the total cubic-foot (cubic-meter) volume from the stump to a 4-inch (10.2-cm) top for a tree of 1.0 square foot (0.0929 m^2) basal area at d.b.h. (Chambers and Foltz 1980). Height trees are used for determining average tarif numbers.

[2] Weighted average, weighted by number of height trees per plot.

Results and Discussion

Site Determination

Site index as expressed here is the average height of the dominant and codominant trees of a given stand at 100 years of age. In mixed stands of Sitka spruce and western hemlock, however, several problems associated with determining site index are apparent. First, the height growth characteristics of Sitka spruce and western hemlock differ considerably (Allen 1902, Cary 1922, Taylor 1934). Barnes (1962) noted that Sitka spruce continues to grow much faster than does western hemlock after 100 years. In addition, the height-age relationship varies significantly between geographic regions. Thus, existing site index curves, such as those constructed by Meyer (1937) for Sitka spruce and western hemlock, are no longer a reliable measure of site index (Barnes 1962).

The average total height of dominant and codominant western hemlock by plot and year is given in table 4. A curve of height over diameter was fitted for the dominant and codominant western hemlocks for each measurement year (fig. 3). From these equations and the average diameter of the dominant and codominant trees, the average total height of the dominant and codominant trees was determined. Barnes' (1962) site index curves were interpolated to determine site index for each measurement year; the average site index used in the study was the mean of the estimates for the four periods. There was no distinguishable difference in site index between Barnes' method and ours (fig. 4). The average site index corresponded approximately to site index 144, placing it in site class III.

Table 4—Average total height of dominant and codominant western hemlock trees[1]

Plot[2] number	1935, age 83			1940, age 89			1945, age 94			1955, age 104			1968, age 116		
	Height		Number of trees	Height		Number of trees	Height		Number of trees	Height		Number of trees	Height		Number of trees
	Feet	Meters		Feet	Meters		Feet	Meters		Feet	Meters		Feet	Meters	
1	133	40.5	27	141	43.0	23	142	43.3	22	147	44.8	22	152	46.3	36
2[3]															
3	145	44.2	9	148	45.1	9	142	43.3	4	158	48.2	1	166	50.6	7
4	122	37.2	5	134	40.8	22	132	40.2	11	140	42.7	4	142	43.3	6
5	0	0	0	149	45.4	1	149	45.4	1	0	0	0	124	37.8	1
6	137	41.8	14	140	42.7	13	132	40.2	11	151	46.0	15	4/	4/	4/
7	129	39.3	10	137	41.8	11	143	43.6	15	143	43.6	12	152	46.3	13
8	120	36.6	17	127	38.7	24	129	39.3	18	135	41.1	15	135	41.5	16
9	0	0	0	0	0	0	5/	5/	5/						
10	105	32.0	5	110	33.5	8	113	34.4	7	123	37.5	8	131	39.9	8
12	135	41.1	19	140	42.7	19	146	44.5	18	150	45.7	18	159	48.5	23
13	141	43.0	19	145	44.2	12	144	43.9	17	155	47.2	14	161	49.1	16
Mean[6]	132	40.2		136	41.4		138	42.1		146	44.5		151	46.0	
Site index[7]	146	44.5		144	43.9		142	43.3		144	43.9		142	43.3	

1/ Trees in crown classes 1 and 2.

2/ The 12 plots that were periodically remeasured. Plots 11, 14, 15, and 16 were younger stands with substantial amounts of Douglas-fir and red alder.

3/ Destroyed soon after establishment.

4/ Destroyed in 1962 Columbus Day windstorm.

5/ Accidentally logged.

6/ Weighted average of the total height of all sample trees.

7/ Interpolated from table 2 of Barnes (1962). Average site index = 144 feet (43.9 meters).

Figure 3.—Height-d.b.h. relationship for selected dominant and codominant western hemlock trees by year of measurement Inconsistencies in measurements apparently caused a discrepancy for 1945.

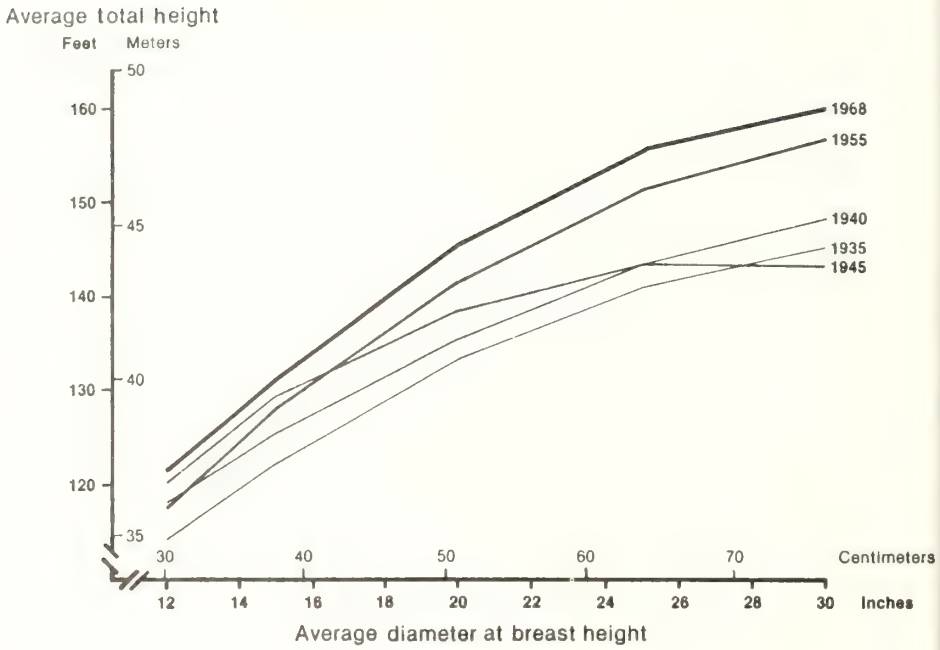
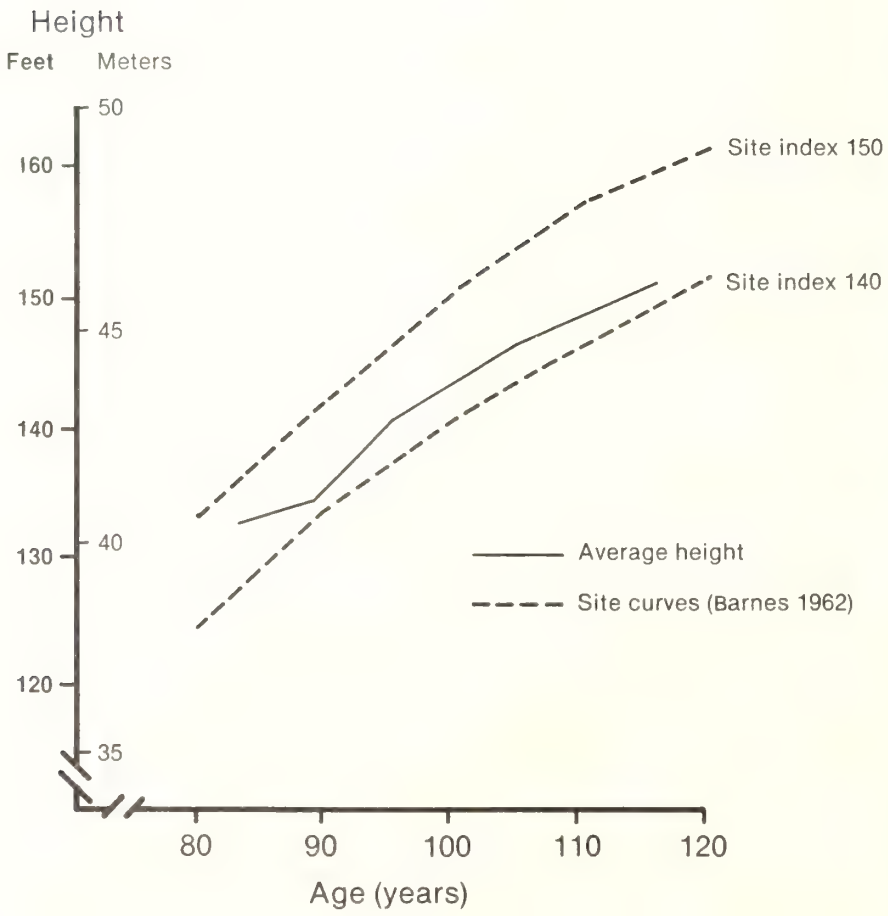


Figure 4.—Average total height of dominant and codominant western hemlock trees Average site index at age 100 years = 144 feet (43.9 m)



Average Total Height

The analysis of the height growth data presented in tables 5 and 6 in the appendix indicates a significant difference in height between Sitka spruce and western hemlock for the 5 measurement years. The average height differential between Sitka spruce and western hemlock ranged from 11 feet (3.3 m) at age 83 to 22 feet (6.7 m) at age 116. Clearly, Sitka spruce had attained a dominant position in the stand at age 116, reaching an average total height of 161 feet (49.1 m). Figure 5 shows the average total height of western hemlock, Sitka spruce, Douglas-fir, and all species for the 5 measurement years.

Although Douglas-fir is represented as an associated species on several of the growth plots, it is widely scattered throughout the study plots. Since only a few height measurements were taken on Douglas-fir, the height data are perhaps unrealistic. Therefore, no further analysis of the height data was attempted, other than that found in figure 5 and tables 5 and 6 in the appendix. Similarly, other measurement data may not represent the true growth characteristics of Douglas-fir; however, observations indicate that Douglas-fir is not maintaining its dominant position in the study plots at Cascade Head and is, for the most part, undersized and poorly developed.

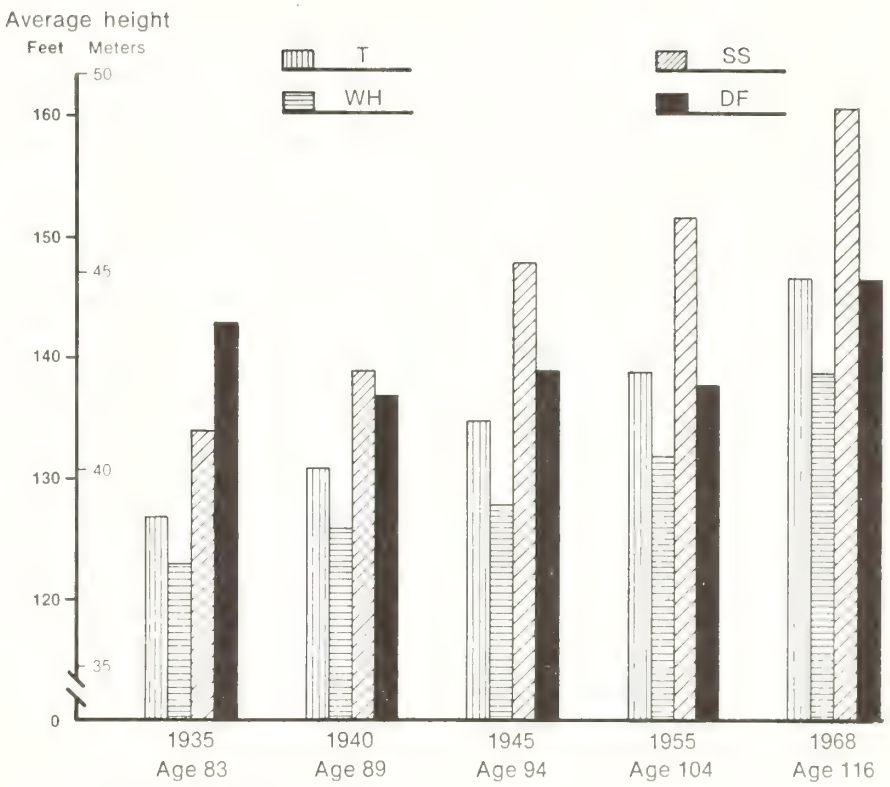


Figure 5.—Average total height of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement (all trees 1.6+ inches (4+ cm) in d.b.h.).

Basal Area

The shade-tolerant nature of both Sitka spruce and western hemlock has resulted in a dense, even-aged stand of exceptionally high basal area (fig. 6).

Total basal area ranged from 417 ft^2/acre (95.8 m^2/ha) at age 83 to 468 ft^2/acre (107.4 m^2/ha) at age 116; basal areas of individual plots ranged from 361 to 518 ft^2/acre (82.8 to 118.9 m^2/ha) at age 116 (appendix tables 7 to 16).

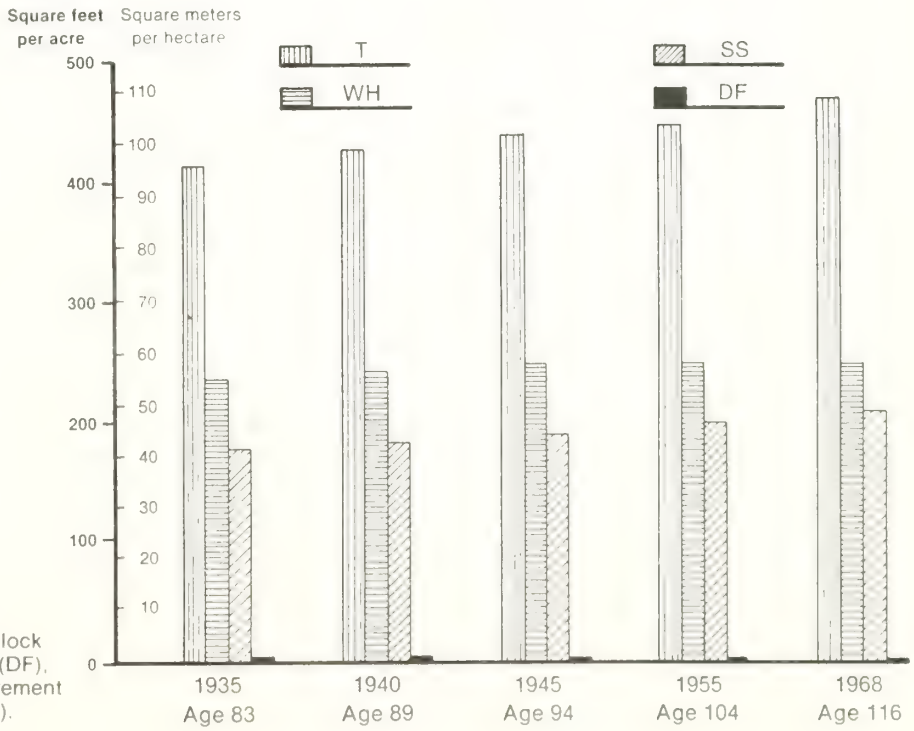


Figure 6.—Basal area of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement (all trees 1.6+ inches (4+ cm) in d.b.h.).

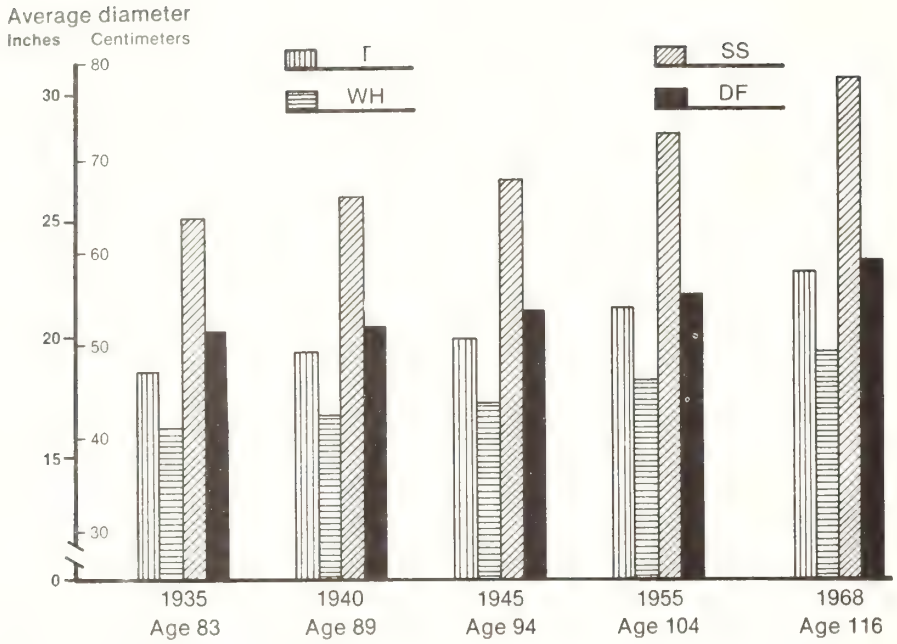


Figure 7.—Average diameter at breast height of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement (all trees 1.6+ inches (4+ cm) in d.b.h.).

Average basal area for western hemlock ranged from 237 ft^2/acre (54.4 m^2/ha) at age 83 to 252 ft^2/acre (57.8 m^2/ha) at age 116. Average basal area for Sitka spruce ranged from 176 ft^2/acre (40.5 m^2/ha) at age 83 to 213 ft^2/acre (48.8 m^2/ha) at age 116. The relatively stable figure for basal area for western hemlock can be attributed to a gradual decrease in the number of trees per acre (ha) and the increased average diameter of the remaining trees. Average basal area for Douglas-fir remained small and essentially unchanged from 1935 to 1968.

Average Diameter

The diameter growth data (appendix tables 7 to 16) reflect an inherent difference between the growth pattern of Sitka spruce and western hemlock. Sitka spruce typically has a rapid and well-sustained growth habit, whereas western hemlock generally grows at a slower rate than its associates (Allen 1902, Meyer 1937). Figure 7 depicts the average diameter[3] for western hemlock, Sitka spruce, Douglas-fir, and all species for each year of measurement.

The larger average diameter of Sitka spruce is apparent, ranging from 25.1 inches (63.8 cm) in d.b.h. at age 83 to 30.6 inches (78 cm) at age 116; western hemlock ranges from 16.2 inches (41 cm) in d.b.h. at age 83 to 19.4 inches (49.3 cm) at age 116. An analysis of the average diameter indicates that Sitka spruce is significantly larger than western hemlock each year of measurement.

[3] Quadratic mean diameter.

Diameter at breast height for Sitka spruce averages 8.9 inches (22.8 cm) or 55 percent larger than western hemlock at age 83 and averages 11.2 inches (28.4 cm) or 58 percent larger at 116. Although Sitka spruce is significantly larger than western hemlock, measurements of diameter are often confounded by extreme butt swell. Diameter differences at 18 feet (5.5 m) above seedling origin might not be so great.

Number of Trees

Figure 8 shows the average number of western hemlock, Sitka spruce, Douglas-fir, and all species per unit area. The total number of trees per acre (ha) decreased from 218 (539) at age 83 to 166 (410) at age 116. Sitka spruce decreased from 51 trees/acre (126/ha) at age 83 to 43/acre (104/ha) at age 116, whereas western hemlock averaged 165 trees/acre (408/ha) at age 83, decreasing to 123/acre (304/ha) at age 116.

Full stocking on the sample areas was maintained throughout the 1935-68 measurement period. Because western hemlock is relatively shade-tolerant and Sitka spruce maintains a high growth rate, and therefore a dominant position beyond 100 years of age (Barnes 1962), the growing sites were fully occupied. In the mixed even-aged stand of Sitka spruce-western hemlock, the larger number of hemlock trees per unit area can probably be traced to the initial establishment of the stand. Western hemlock is a constant and prolific seeder, but Sitka spruce seeds only occasionally (Meyer 1937). Thus, western hemlock had an advantage over Sitka spruce in numbers of trees per unit area. That numerical advantage is still apparent today.

Figures 9-11 compare the distribution of the number of trees per acre (ha) by 2-inch (5.1-cm) diameter class for western hemlock, Sitka spruce, and all species at ages 83 and 116. Table 17 (appendix) gives stand information for each year of measurement.

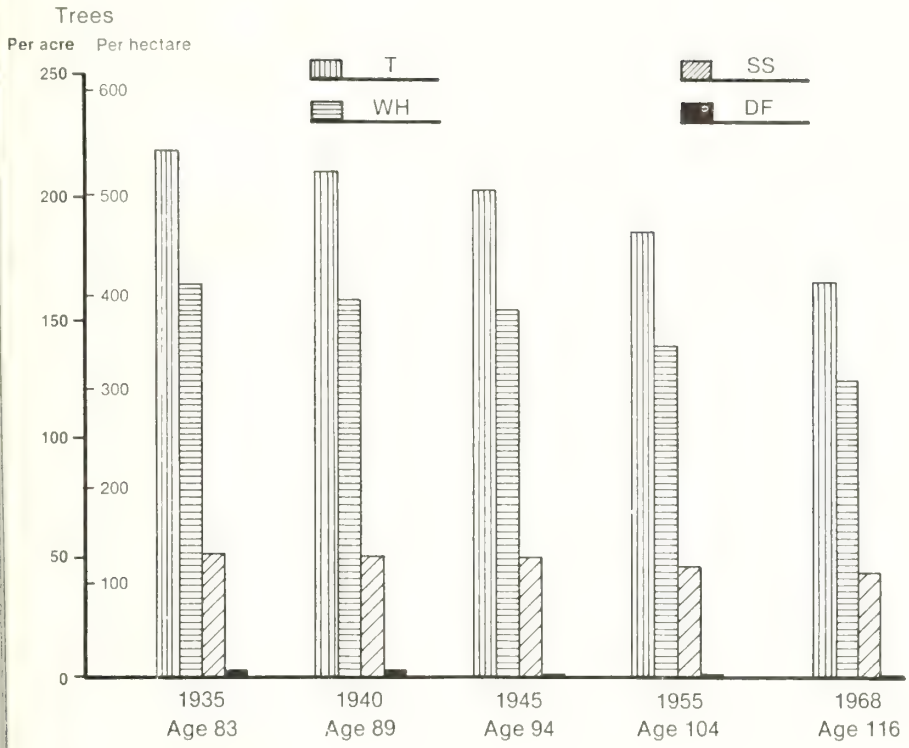


Figure 8.—Number of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement (trees 1.6+ inches (4+ cm) in d.b.h.)

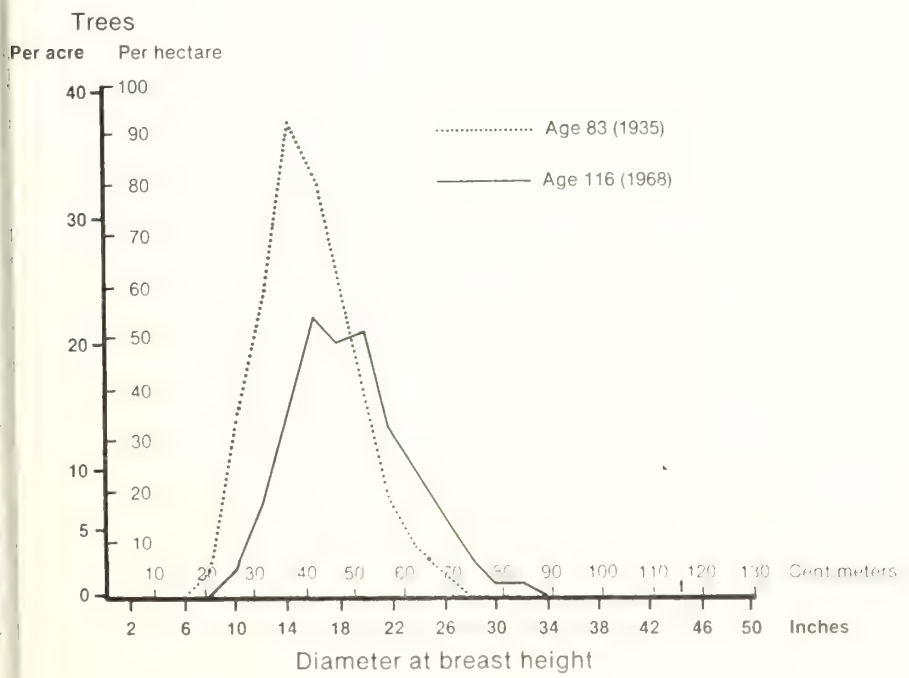


Figure 9.—Distribution of western hemlock trees by 2-inch (5-cm) diameter class (trees 1.6+ inches (4+ cm) in d.b.h.).

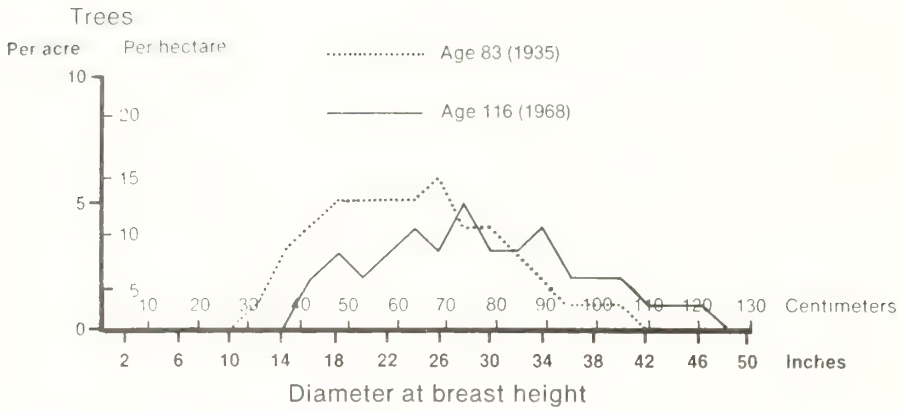


Figure 10.—Distribution of Sitka spruce trees by 2-inch (5-cm) diameter class (trees 1.6+ inches (4+ cm) in d.b.h.).

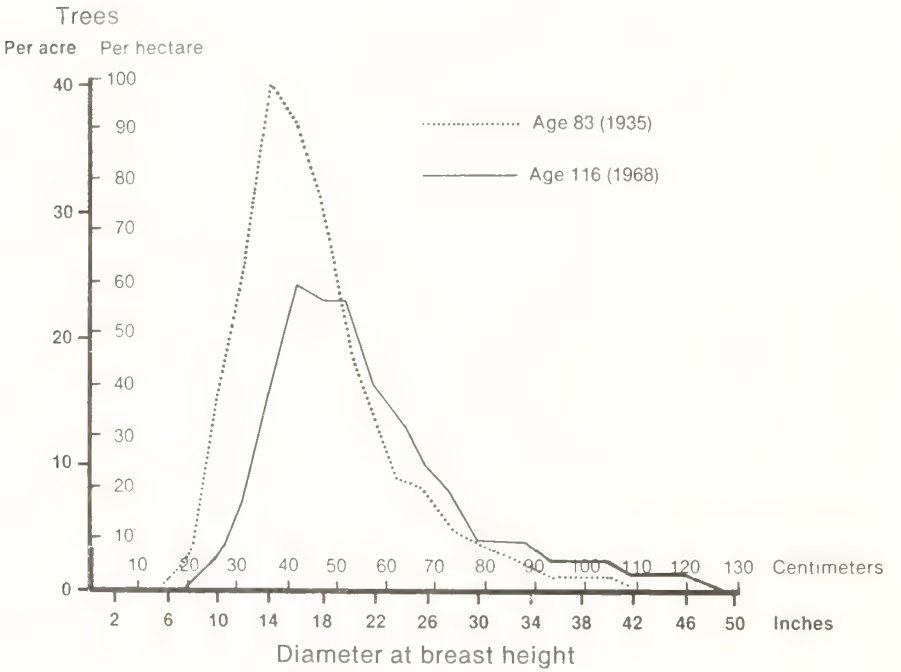


Figure 11.—Distribution of all species by 2-inch (5-cm) diameter class (trees 1.6+ inches (4+ cm) in d.b.h.).

Volume of Wood

The ability of mixed stands of Sitka spruce and western hemlock to produce the yields of wood shown in figures 12-14 reflects their tremendous potential for production of sawtimber and wood fiber. These remarkable yields can be attributed, in part, to the complimentary growth habit of both species and favorable site conditions. A high productive capacity is indicated. Western hemlock shows a slightly greater productive advantage over Sitka spruce for both cubic-foot and board-foot (International 1/4-inch rule) volumes, primarily because of the smaller merchantable diameter limits and the larger number of smaller western hemlock trees per acre (ha). For board-foot volume (Scribner rule), Sitka spruce and western hemlock show almost identical yields. Figures 12-14 give average gross volumes with no allowances for defect or breakage. Figure 12 shows the average volumes (Scribner rule) per acre and per hectare for trees 11.6+ inches (29 cm) in d.b.h. to a 6-inch (15-cm) top diameter. Total volume per acre increased from an average of 121,684 board feet at age 83 to 162,933 at age 116; individual plot totals ranged from 95,878 to 167,439 board feet per acre at age 83 to 131,515 to 191,865 at age 116 (appendix tables 18 to 27). Board-foot (International 1/4-inch rule) volume per acre for trees 6.6+ inches (17 cm) in d.b.h. to a 6.0-inch (15-cm) merchantable top diameter is given in figure 13. Total volume per unit area rose from 138,522 board feet per acre at age 83 to 178,957 at age 116. Individual plot total volumes ranged from 112,812 to 179,040 board feet per acre at age 83 to 146,864 to 205,342 board feet per acre at age 116.

Figure 14 shows cubic volumes per acre and hectare for trees 5.6+ inches (14+ cm) in d.b.h. to a 4.0-inch (10.2-cm) top diameter. Total volume increased from 20,932 ft^3/acre (1465 m^3/ha) at age 83 to 26,280 ft^3/acre (1839 m^3/ha) at age 116.

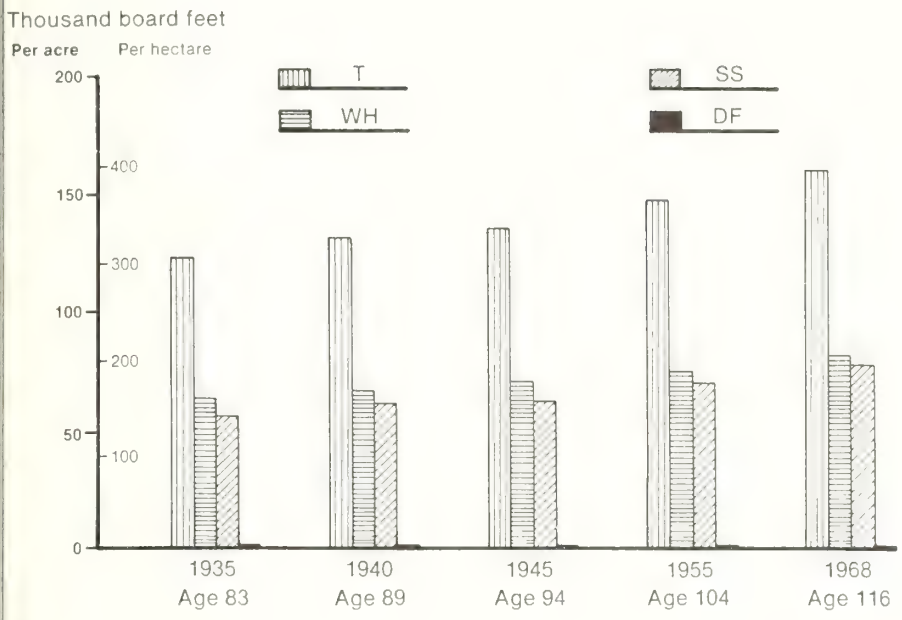


Figure 12.—Volume (Scribner rule) of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement.

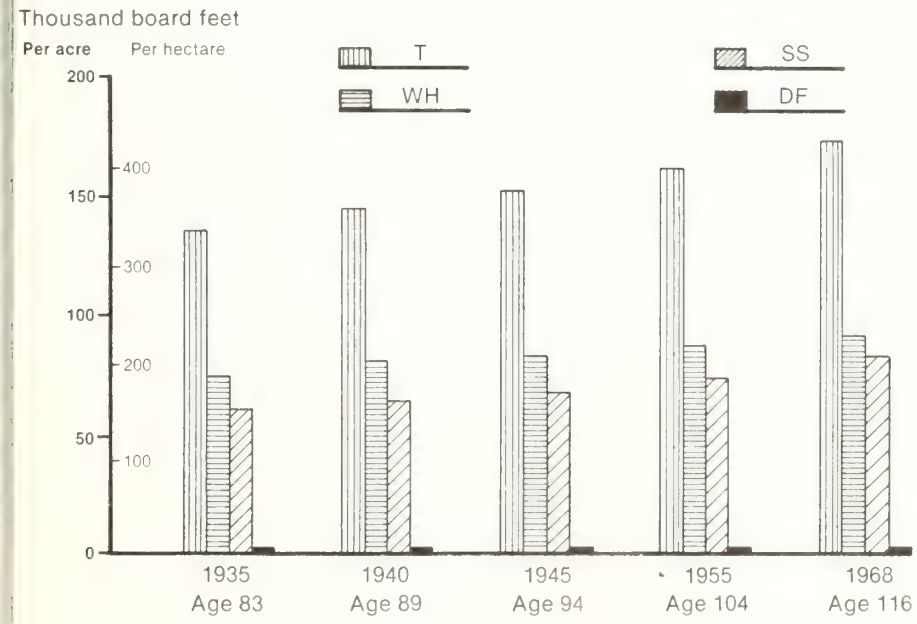


Figure 13.—Volume (International 1/4-inch rule) of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement.

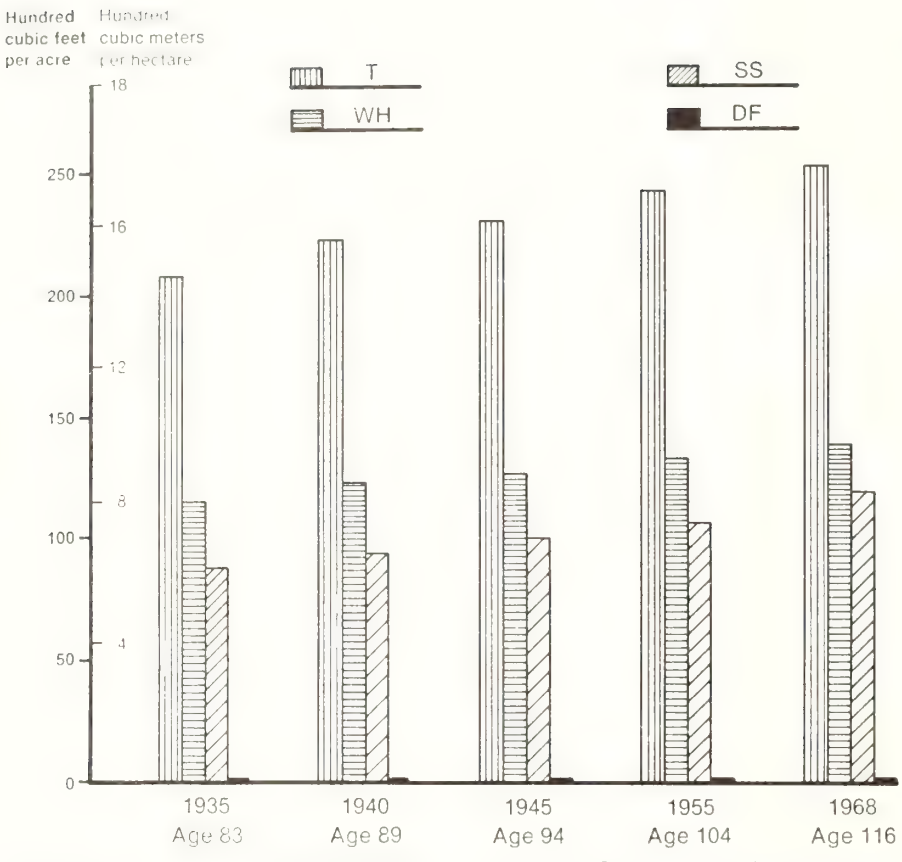


Figure 14.—Cubic volume of western hemlock (WH), Sitka spruce (SS), Douglas-fir (DF), and all species (T), by year of measurement

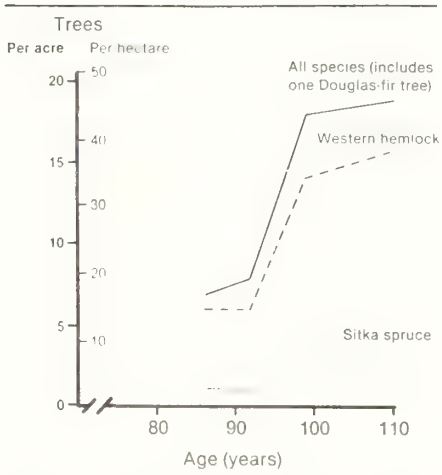


Figure 15.—Mortality of trees 1.6+ inches (4+ cm) in d.b.h., 1935-68 (based on plots measured five times—plots 6 and 9 omitted)

Mortality

Mortality for the permanent sample plots is shown in figure 15. Average mortality per acre (ha) ranged from slightly more than 7 trees/acre (18/ha) between ages 83 and 89 to 19/acre (47/ha) between ages 104 and 116 (appendix tables 28-29). A field measure in 1950 indicated that suppression and windfall were the primary causes of mortality, suppression contributing 79 percent of the total loss. Western hemlock has a higher rate of mortality than Sitka spruce (fig. 15). As the larger, dominant spruce subordinates the smaller, more tolerant hemlock, the weaker suppressed and intermediate hemlocks are eliminated from the stand.

Both Sitka spruce and western hemlock are species with shallow roots highly susceptible to windthrow (Meyer 1937). In fact, plot 6, which consisted of approximately 83 percent hemlock and 16 percent spruce, was completely destroyed during the 1962 Columbus Day windstorm.

Tree Growth

Estimates of mean annual and periodic annual gross increments per unit area for the study plots are given in appendix tables 30 and 31. Figures 16-18 give mean annual increment (MAI) and periodic annual increment (PAI) per acre for each species in board feet (International 1/4-inch and Scribner rules) and cubic feet.

The remarkably consistent growth habit of Sitka spruce is apparent. Mean annual increment for Sitka spruce averages 737 board feet per acre (International 1/4-inch rule) at age 83 and only decreases to 724 board feet at age 116, a reduction in annual growth of less than 2 percent. The MAI for western hemlock averages 915 board feet (International 1/4-inch rule) per acre at age 83 and decreases to 808 at age 116, a reduction of nearly 12 percent. The MAI for all species ranges from 1,669 board feet (International 1/4-inch rule) per acre at age 83 to 1,543 at age 116, the average growth rate declining only about 7 percent over the 33 years of measurement.

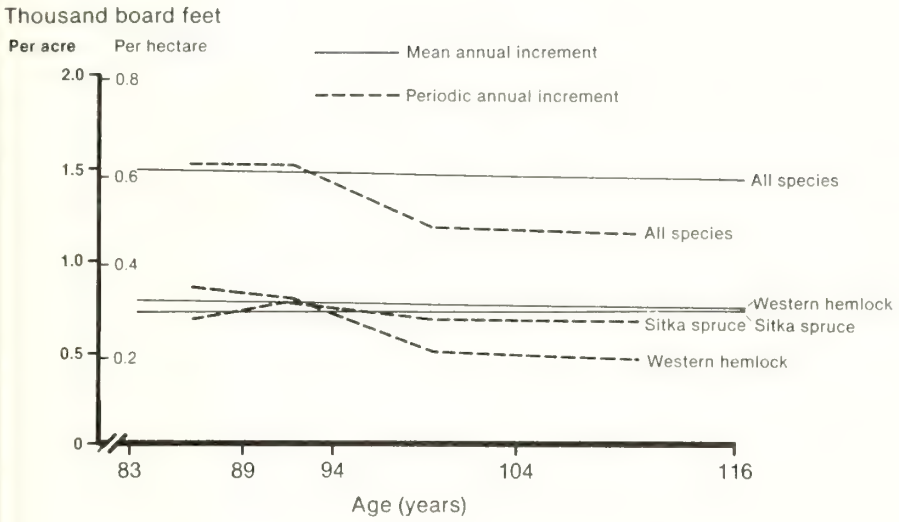


Figure 16.—Annual and periodic board-foot (Scribner rule) growth of trees 11.6 inches (29.5 cm) in d.b.h. to a 6-inch (15.2-cm) top diameter

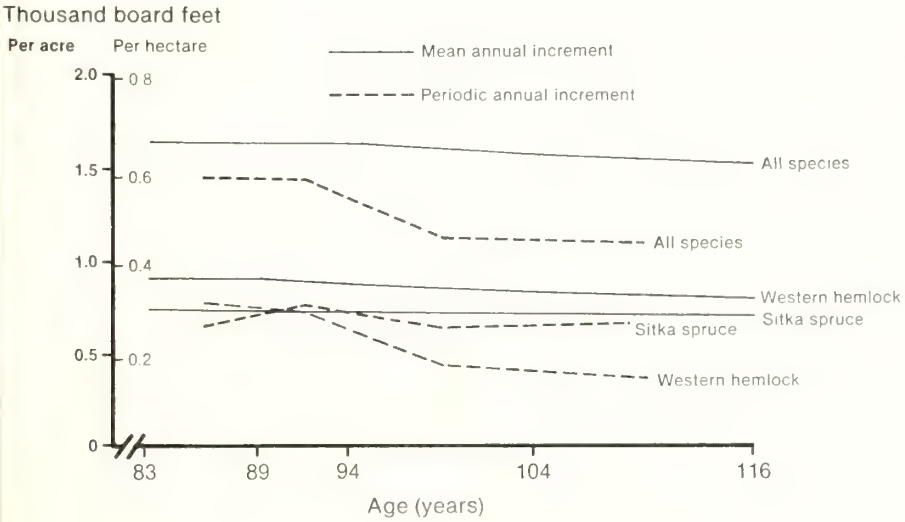


Figure 17.—Annual and periodic board-foot (International 1/4-inch rule) growth of trees 6.6+ inches (16.8+ cm) in d.b.h. to a 6-inch (15.2-cm) top diameter

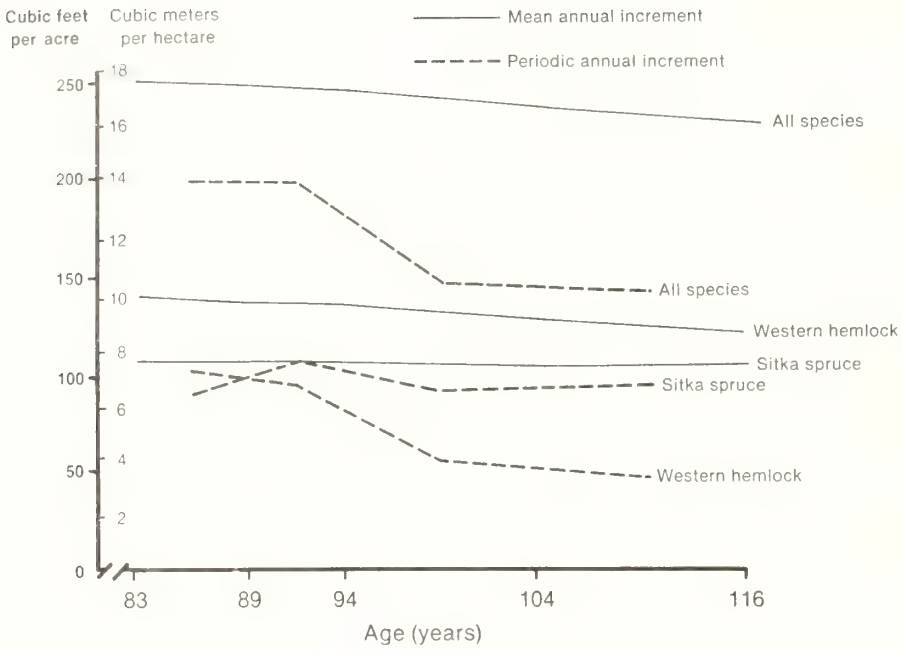


Figure 18.—Annual and periodic cubic volume growth of trees 5.6+ inches (14.2+ cm) in d.b.h. to a 4-inch (10.2-cm) top diameter.

Total wood production is at or near its maximum for the mixed stands of western hemlock and Sitka spruce at Cascade Head, but the culmination of MAI is not clearly defined for either species. Periodic annual increment is declining in relation to stand age. The sharp drop in PAI between the ages of 94 and 116 can be attributed to a corresponding reduction in the number of trees per acre (ha), especially in the intermediate and suppressed western hemlock crown classes. Periodic annual increment ranges from 789 board feet (International 1/4-inch rule) per acre to 396 for western hemlock between the ages of 83 and 116. For Sitka spruce, PAI appears to culminate at 776 board feet (International 1/4-inch rule) per acre between the ages of 89 and 94 and decreases gradually to 689 board feet between the ages of 104 and 116.

These data agree with the previous claim that the Sitka spruce-western hemlock type is among the most productive coniferous types in the world (Fujimori 1971).

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Appendix

Tables 5 to 31

Table 5—Summary of average height of selected trees, 1.6+ inches in d.b.h., 1935-68

Plot[1]	Western hemlock		Sitka spruce		Douglas-fir		All species		Western hemlock		Sitka spruce		Douglas-fir		All species	
	Height	No. of trees	Height	No. of trees	Height	No. of trees	Average height	No. of trees	Height	No. of trees	Height	No. of trees	Height	No. of trees	Average height	No. of trees
	Feet		Feet		Feet		Feet		Feet		Feet		Feet		Feet	
				1935								1940				
1	127	39	0	0	147	1	127	40	130	42	117	4	151	1	129	47
3	135	19	151	23	0	0	144	42	138	17	161	15	0	0	149	32
4	106	19	131	20	0	0	119	39	110	10	142	33	0	0	134	43
5	119	9	142	27	0	0	136	36	128	10	155	32	150	1	148	43
6	129	23	129	8	0	0	129	31	127	31	135	10	135	1	129	42
7	124	24	134	13	139	1	128	38	123	29	146	9	130	4	129	42
8	115	31	138	1	0	0	116	32	120	44	0	0	0	0	120	44
9	0	0	118	24	0	0	118	24	0	0	123	46	0	0	123	46
10	96	17	121	33	0	0	110	39	105	21	128	22	0	0	117	43
12	130	30	138	10	0	0	132	40	133	33	141	10	0	0	135	43
13	134	28	142	8	0	0	136	36	132	35	148	9	0	0	135	44
Total		239		156		2		397		272		190		7		469
Mean[2]	123		134		143		127		126		139		137		131	
				1945								1955				
1	133	41	0	0	0	0	133	41	137	37	137	3	165	1	138	41
3	134	21	162	33	0	0	151	54	142	26	170	22	0	0	155	48
4	107	11	137	28	0	0	128	39	115	16	144	30	131	3	133	49
5	127	10	155	31	0	0	148	41	129	10	160	32	149	1	152	43
6	124	29	141	9	0	0	128	38	139	30	151	12	135	1	142	43
7	132	30	152	10	139	1	137	41	129	27	145	12	136	4	134	43
8	124	41	0	0	0	0	124	41	123	34	147	2	0	0	124	36
9[3]																
10	103	23	130	22	0	0	116	45	117	26	139	25	0	0	128	51
12	139	24	148	9	0	0	141	33	140	28	148	12	0	0	142	40
13	137	30	150	9	0	0	140	39	142	28	163	8	0	0	147	36
Total		260		151		1		412		262		258		10		430
Mean[2]	128		148		139		135		132		152		138		139	
				1968												
1	143	53	142	3	164	1	144	57								
3	156	19	178	11	0	0	164	30								
4	124	15	153	24	141	1	142	40								
5	132	12	170	30	154	1	159	43								
6[4]																
7	135	28	160	11	142	4	142	43								
8	125	32	137	3	0	0	126	35								
10	127	20	149	26	0	0	140	46								
12	149	33	164	9	0	0	152	42								
13	148	31	172	10	0	0	154	41								
Total		243		127		7		377								
Mean[2]	139		161		147		147									

[1] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Weighted average, based on average height of trees on the plot times the number of observations per plot, summed over all plots with height measurements, and divided by the total number of observations.

[3] Plot 9 was destroyed by accidental logging.

[4] Plot 6 was destroyed by the 1962 Columbus Day storm.

Table 6—Summary of average height of selected trees, 4+ centimeters in d.b.h., 1935-68

Plot[1]	Western hemlock		Sitka spruce		Douglas-fir		All species		Western hemlock		Sitka spruce		Douglas-fir		All species	
	Height	No. of trees	Height	No. of trees	Height	No. of trees	Average height	No. of trees	Height	No. of trees	Height	No. of trees	Height	No. of trees	Average height	No. of trees
	1935								1940							
	Meters		Meters		Meters		Meters		Meters		Meters		Meters		Meters	
1	38.7	39	0	0	44.8	1	38.7	40	39.6	42	35.7	4	46.0	1	39.3	47
3	41.1	19	46.0	23	0	0	43.9	42	42.1	17	49.1	15	0	0	45.4	32
4	32.3	19	39.9	20	0	0	36.9	39	33.5	10	43.3	33	0	0	40.8	43
5	36.3	9	43.3	27	0	0	41.5	36	39.0	10	47.2	32	45.7	1	45.1	43
6	39.3	23	39.3	8	0	0	39.3	31	38.7	31	41.1	10	41.1	1	39.3	42
7	37.8	24	40.8	13	42.4	1	39.0	38	37.5	29	44.5	9	39.6	4	39.3	42
8	35.1	31	42.1	1	0	0	35.4	32	36.6	44	0	0	0	0	36.6	44
9	0	0	36.0	24	0	0	36.0	24	0	0	37.5	46	0	0	37.5	46
10	29.3	17	36.9	33	0	0	33.5	39	32.0	21	39.0	22	0	0	35.7	43
12	39.6	30	42.0	10	0	0	40.2	40	40.5	33	43.0	10	0	0	41.1	43
13	40.8	28	43.3	8	0	0	41.5	36	40.2	35	45.1	9	0	0	41.1	44
Total		239		156		2		397		272		190		7		469
Mean[2]	37.5		40.8		43.6		38.7		38.4		42.4		41.8		39.9	
	1945								1955							
1	40.5	41	0	0	0	0	40.5	41	41.8	37	41.8	3	50.3	1	42.1	41
3	40.8	21	49.4	33	0	0	46.0	54	43.3	26	51.8	22	0	0	47.2	48
4	32.6	11	41.8	28	0	0	39.0	39	35.1	16	43.9	30	39.9	3	40.5	49
5	38.7	10	47.2	31	0	0	45.1	41	39.3	10	48.8	32	45.4	1	46.3	43
6	37.8	29	43.0	9	0	0	39.0	38	42.4	30	46.0	12	39.0	1	43.3	43
7	40.2	30	46.3	10	42.4	1	41.8	41	39.3	27	44.2	12	41.5	4	40.8	43
8	37.8	41	0	0	0	0	37.8	41	37.5	34	44.8	2	0	0	37.8	36
9[3]																
10	31.4	23	39.6	22	0	0	35.4	45	35.7	26	42.4	25	0	0	39.0	51
12	42.4	24	45.1	9	0	0	43.0	33	42.7	28	45.1	12	0	0	43.3	40
13	41.8	30	45.7	9	0	0	42.7	39	43.3	28	49.7	8	0	0	44.8	36
Total		260		151		1		412		262		258		10		430
Mean[2]	39.0		45.1		42.4		41.1		40.2		46.3		42.1		42.4	
	1968															
1	43.6	53	43.3	3	50.0	1	43.9	57								
3	47.5	19	54.3	11	0	0	50.0	30								
4	37.8	15	46.6	24	43.0	1	43.3	40								
5	40.2	12	51.8	30	46.9	1	48.5	43								
6[4]																
7	41.2	28	48.8	11	43.3	4	43.3	43								
8	38.1	32	41.8	3	0	0	38.4	35								
10	38.7	20	45.4	26	0	0	42.7	46								
12	45.4	33	50.0	9	0	0	46.3	42								
13	45.1	31	52.4	10	0	0	46.9	41								
Total		243		127		7		377								
Mean[2]	42.4		49.1		44.8		44.8									

[1] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Weighted average, based on average height of trees on the plot times the number of observations per plot, summed over all plots with height measurements, and divided by the total number of observations.

[3] Plot 9 was destroyed by accidental logging.

[4] Plot 6 was destroyed by the 1962 Columbus Day storm.

Table 7—Stand description at age 83 in 1935, in English units[1/]

Plot[2/]	Basal area per acre[3/]				Diameter[4/]				Trees per acre[3/]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5/]
	Square feet				Inches				Number				
1	407.2	9.9	3.4	420.5	16.9	17.4	25.0	17.0	260	6	1	267	97
3	153.3	264.0	.9	418.3	17.7	25.2	12.8	21.4	90	76	1	167	54
4	76.4	346.7	8.7	431.7	14.6	22.8	20.0	20.3	66	122	4	192	34
5	52.7	427.7	4.1	484.6	16.4	26.2	27.4	24.3	36	114	1	151	24
6	292.3	97.9	3.2	393.4	17.7	23.0	17.1	18.7	171	34	2	207	83
7	296.7	116.5	18.7	431.9	16.4	22.0	19.5	17.6	202	44	9	255	79
8	427.1	10.3	0	437.4	14.9	21.7	0	15.0	352	4	0	356	99
9	0	517.8	0	517.8	0	24.4	0	24.4	0	160	0	160	0
10	157.5	264.7	0	422.2	15.9	31.8	0	21.9	114	48	0	162	70
12	268.1	92.6	0	360.7	17.1	23.4	0	18.2	168	31	0	199	84
13	292.3	54.4	0	346.7	16.3	23.5	0	17.0	201	18	0	219	92
Mean[6/]	236.8	176.3	4.0	417.1	16.2	25.1	20.3	18.7	165	51	2	218	76

[1/] WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2/] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3/] Based on plot area of 1 horizontal acre.

[4/] Quadratic mean diameter.

[5/] Percent of western hemlock in designated plot.

[6/] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 8—Stand description at age 83 in 1935, in metric units[1]

Plot[2/]	Basal area per hectare[3/]				Diameter[4/]				Trees per hectare[3/]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5/]
	Square meters				Centimeters				Number				
1	93.5	2.3	0.8	96.5	42.9	44.2	63.5	43.2	642	15	2	660	97
3	35.2	60.6	.2	96.0	45.0	64.0	32.5	54.4	222	188	2	413	54
4	17.5	79.6	2.0	99.1	37.1	57.9	50.8	51.6	163	301	10	474	34
5	12.1	98.2	.9	111.2	41.7	66.5	69.6	61.7	89	282	2	373	24
6	67.1	22.5	.7	90.3	45.0	58.4	43.4	47.5	423	84	5	511	83
7	68.1	26.7	4.3	99.1	41.7	55.9	49.5	44.7	499	109	22	630	79
8	98.0	2.4	0	100.4	37.8	55.1	0	38.1	870	10	0	880	99
9	0	118.9	0	118.9	0	62.0	0	62.0	0	395	0	395	0
10	36.2	60.8	0	96.9	40.4	80.8	0	55.6	282	119	0	400	70
12	61.5	21.3	0	82.8	43.4	59.4	0	46.2	415	77	0	492	80
13	67.1	12.5	0	79.6	41.4	59.7	0	43.2	497	44	0	541	92
Mean[6/]	54.4	40.5	.9	95.8	41.1	63.8	51.6	47.5	408	126	5	539	76

[1/] WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2/] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3/] Based on plot area of 1 horizontal hectare.

[4/] Quadratic mean diameter.

[5/] Percent of western hemlock in designated plot.

[6/] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 9—Stand description at age 89 in 1940, in English units[1]

Plot[2]	Basal area per acre[3]				Diameter[4]				Trees per acre[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square feet				Inches				Number				
1	423.1	9.2	3.6	435.9	17.5	18.4	25.7	17.6	253	5	1	259	98
3	154.4	267.7	.9	423.1	18.5	26.3	12.8	22.4	83	71	1	155	54
4	80.3	362.5	9.1	451.8	15.1	23.6	20.4	21.0	65	119	4	188	34
5	55.0	439.8	4.2	499.0	16.7	26.8	27.7	24.8	36	112	1	149	24
6	303.3	100.6	3.4	407.3	18.5	24.4	17.7	19.5	163	31	2	196	83
7	310.0	121.4	19.0	450.4	16.9	23.0	19.7	18.2	198	42	9	249	80
8	432.0	10.9	0	442.9	15.5	22.4	0	15.6	329	4	0	333	99
9	0	514.1	0	514.1	0	25.1	0	25.1	0	150	0	150	0
10	149.7	280.6	0	430.2	16.6	32.7	0	23.1	100	48	0	148	68
12	284.6	98.3	0	382.8	17.7	24.5	0	18.9	166	30	0	196	85
13	306.6	56.8	0	363.4	16.9	25.5	0	17.7	197	16	0	213	92
Mean[6]	244.0	183.0	4.1	431.1	16.8	26.0	20.5	19.4	159	50	2	211	75

[1] WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3] Based on plot area of 1 horizontal acre.

[4] Quadratic mean diameter.

[5] Percent of western hemlock in designated plot.

[6] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 10—Stand description at age 89 in 1940, in metric units[1]

Plot[2]	Basal area per hectare[3]				Diameter[4]				Trees per hectare[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square meters				Centimeters				Number				
1	97.1	2.1	0.8	100.1	44.5	46.7	65.3	44.7	625	12	2	640	98
3	35.4	61.5	.2	97.1	47.0	66.8	32.5	56.9	205	175	2	383	54
4	18.4	83.2	2.1	103.7	38.4	59.9	51.8	53.3	161	294	10	465	34
5	12.6	101.0	1.0	114.5	42.4	68.1	70.4	63.0	89	277	2	368	24
6	69.6	23.1	.8	93.5	47.0	62.0	45.0	49.5	403	77	5	484	83
7	71.2	27.9	4.4	103.4	42.9	58.4	50.0	46.2	489	104	22	615	80
8	99.2	2.5	0	101.7	39.4	56.9	0	39.6	813	10	0	823	99
9	0	118.0	0	118.0	0	63.8	0	63.8	0	371	0	371	0
10	34.4	64.4	0	98.8	42.2	83.1	0	58.7	247	119	0	366	68
12	65.3	22.6	0	87.9	45.0	62.2	0	48.0	410	74	0	484	85
13	70.4	13.0	0	83.4	42.9	64.8	0	45.0	487	40	0	526	92
Mean[6]	56.0	42.0	.9	99.0	42.7	66.0	52.1	49.3	393	124	5	521	75

[1] WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3] Based on plot area of 1 horizontal hectare.

[4] Quadratic mean diameter.

[5] Percent of western hemlock in designated plot.

[6] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 11—Stand description at age 94 in 1945, in English units[1]

Plot[2]	Basal area per acre[3]				Diameter[4]				Trees per acre[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square feet				Inches				Number				
1	463.3	8.5	3.8	448.6	18.1	19.7	26.4	18.2	244	4	1	249	98
3	156.0	281.0	.9	437.9	19.1	27.1	12.8	23.2	78	70	1	149	52
4	84.1	362.5	9.2	469.6	15.4	24.3	20.5	21.5	65	117	4	186	35
5	56.3	448.2	4.3	508.8	17.2	27.3	28.1	25.3	35	110	1	146	24
6	309.6	105.5	3.4	418.5	19.1	25.4	17.7	20.3	155	30	2	187	83
7	316.0	125.3	13.4	454.7	17.4	23.7	20.2	18.7	192	41	6	239	80
8	443.7	11.6	0	455.2	16.0	23.1	0	16.1	317	4	0	321	99
10	153.7	294.6	0	448.3	16.9	33.5	0	23.6	99	48	0	147	67
12	282.0	103.2	0	385.3	18.3	25.5	0	19.6	155	29	0	184	84
13	312.0	61.6	0	373.7	17.4	26.6	0	18.3	189	16	0	205	92
Mean[6]	248.9	190.0	3.5	442.5	17.3	26.7	21.1	20.0	153	49	1	203	75

1/ WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

2/ Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

3/ Based on plot area of 1 horizontal acre.

4/ Quadratic mean diameter.

5/ Percent of western hemlock in designated plot.

6/ Based on plots intact in 1968--plot 6 omitted.

Table 12—Stand description at age 94 in 1945, in metric units[1]

Plot[2]	Basal area per hectare[3]				Diameter[4]				Trees per hectare[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square meters				Centimeters				Number				
1	106.4	2.0	0.9	103.0	46.0	50.0	67.1	46.2	603	10	2	615	98
3	35.8	64.5	.2	100.5	48.5	68.8	32.5	58.9	193	173	2	368	52
4	19.3	83.2	2.1	107.8	39.1	61.7	52.1	54.6	161	289	10	460	35
5	12.9	102.9	1.0	116.8	43.7	69.3	71.4	64.3	86	272	2	361	24
6	71.1	24.2	.8	96.1	48.5	64.5	45.0	51.6	383	74	5	462	83
7	72.5	28.8	3.1	104.4	44.2	60.2	51.3	47.5	474	101	15	591	80
8	101.9	2.7	0	104.5	40.6	58.7	0	40.9	783	10	0	793	99
10	35.3	67.6	0	103.0	142.9	85.1	0	59.9	1245	119	0	363	67
12	64.7	23.7	0	88.4	146.5	64.8	0	49.8	1383	72	0	455	84
13	71.6	14.1	0	85.8	144.2	67.6	0	46.5	1467	40	0	507	92
Mean[6]	57.1	43.6	.8	101.6	43.9	67.8	53.6	50.8	378	121	2	502	75

1/ WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

2/ Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

3/ Based on plot area of 1 horizontal hectare.

4/ Quadratic mean diameter.

5/ Percent of western hemlock in designated plot.

6/ Based on plots intact in 1968--plot 6 omitted.

Table 13—Stand description at age 104 in 1955, in English units[1]

Plot[2]	Basal area per acre[3]				Diameter[4]				Trees per acre[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square feet				Inches				Number				
1	430.6	8.3	4.1	443.0	19.0	22.5	27.4	19.1	218	3	1	222	98
3	152.2	301.3	0	453.5	20.1	28.7	0	24.7	69	67	0	136	51
4	90.4	399.2	9.6	499.3	16.1	25.7	21.0	22.6	64	111	4	179	36
5	58.2	445.6	4.4	508.2	18.0	29.0	28.4	26.7	33	97	1	131	25
6	325.4	113.9	2.2	441.5	20.0	36.8	20.1	21.3	149	29	1	179	83
7	331.9	138.6	10.7	481.2	18.1	24.9	19.8	19.5	185	41	5	231	80
8	445.0	10.7	0	455.7	16.9	25.6	0	17.0	285	3	0	288	99
10	139.4	321.1	0	460.6	117.5	35.4	0	25.5	83	47	0	130	64
12	299.9	113.6	0	413.5	119.3	27.8	0	20.8	148	27	0	175	84
13	313.6	65.3	0	378.9	118.5	30.3	0	19.6	168	13	0	181	93
Mean[6]	251.2	200.4	3.2	454.9	18.2	28.4	21.9	21.2	139	45	1	185	75

[1] WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2] Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3] Based on plot area of 1 horizontal acre.

[4] Quadratic mean diameter.

[5] Percent of western hemlock in designated plot.

[6] Based on plots intact in 1968--plot 6 omitted.

Table 14—Stand description at age 104 in 1955, in metric units[1]

Plot[2]	Basal area per hectare[3]				Diameter[4]				Trees per hectare[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square meters				Centimeters				Number				
1	98.8	1.9	.9	101.7	48.3	57.2	69.6	48.5	539	7	2	549	98
3	34.9	69.2	0	104.1	51.1	72.9	0	62.7	171	166	0	336	51
4	20.8	91.6	2.2	114.6	40.9	65.3	53.3	57.4	158	274	10	442	36
5	13.4	102.3	1.0	116.7	45.7	73.7	72.1	67.8	82	240	2	324	25
6	74.7	26.1	.5	101.3	50.8	93.5	51.1	54.1	368	72	2	442	83
7	76.2	31.8	2.5	110.5	46.0	63.2	50.3	49.5	457	101	12	571	80
8	102.2	2.5	0	104.6	42.9	65.0	0	43.2	704	7	0	712	99
10	32.0	73.7	0	105.7	44.5	89.9	0	64.8	205	116	0	321	64
12	68.8	26.1	0	94.9	49.0	70.6	0	52.8	366	67	0	432	84
13	72.0	15.0	0	87.0	47.0	77.0	0	49.8	415	32	0	447	93
Mean[6]	57.7	46.0	.7	104.4	46.2	72.1	55.6	53.8	343	111	2	457	75

[1] WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2] Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3] Based on plot area of 1 horizontal hectare.

[4] Quadratic mean diameter.

[5] Percent of western hemlock in designated plot.

[6] Based on plots intact in 1968--plot 6 omitted.

Table 15—Stand description at age 116 in 1968, in English units[1]

Plot[2]	Basal area per acre[3]				Diameter[4]				Trees per acre[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square feet				Inches				Number				
1	423.5	8.8	4.4	436.7	20.2	23.2	28.4	20.3	190	3	1	194	98
3	152.8	319.5	0	472.3	21.3	30.7	0	26.4	62	62	0	124	50
4	92.8	429.5	8.2	530.5	17.6	27.7	22.4	24.6	55	103	3	161	34
5	60.3	452.9	4.7	517.9	19.2	30.7	29.4	28.2	30	88	1	119	25
7	325.6	148.7	12.0	486.4	19.3	27.5	21.0	21.0	161	36	5	202	80
8	457.6	11.7	0	469.3	18.0	26.7	0	18.1	259	3	0	262	99
10	125.4	347.9	0	473.4	19.1	37.2	0	28.2	63	46	0	109	58
12	316.3	120.2	0	436.5	20.6	31.7	0	22.4	137	22	0	159	86
13	313.0	75.3	0	388.3	19.8	32.6	0	21.2	146	13	0	159	92
Mean[6]	251.9	212.7	3.3	467.9	19.4	30.6	23.2	22.8	123	42	1	166	74

[1]/WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2]/Plots 2, 6, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 6 was destroyed by the substantial amounts Columbus Day storm (before remeasurement), plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3]/Based on plot area of 1 horizontal acre.

[4]/Quadratic mean diameter.

[5]/Percent of western hemlock in designated plot.

[6]/Based on plot intact in 1968.

Table 16—Stand description at age 116 in 1968, in metric units[1]

Plot[2]	Basal area per hectare[3]				Diameter[4]				Trees per hectare[3]				
	WH	SS	DF	T	WH	SS	DF	T	WH	SS	DF	T	Percent[5]
	Square meters				Centimeters				Number				
1	97.2	2.0	1.0	100.2	51.3	58.9	72.1	51.6	469	7	2	479	98
3	35.1	73.3	0	108.4	54.1	78.0	0	67.1	153	153	0	306	50
4	21.3	98.6	1.9	121.8	44.7	70.4	56.9	62.5	136	255	7	398	34
5	13.8	104.0	1.1	118.9	48.8	78.0	74.7	71.6	74	217	2	294	25
7	74.7	34.1	2.8	111.7	49.0	69.9	53.3	53.3	398	89	12	499	80
8	105.0	2.7	0	107.7	45.7	67.8	0	46.0	640	7	0	647	99
10	28.8	79.9	0	108.7	48.5	94.5	0	71.6	156	114	0	269	58
12	72.6	27.6	0	100.2	52.3	80.5	0	56.9	339	54	0	393	86
13	71.9	17.3	0	89.1	50.3	82.8	0	53.8	361	32	0	393	92
Mean[6]	57.8	48.8	.8	107.4	49.3	77.7	58.9	57.9	304	104	2	410	74

[1]/WH = western hemlock; SS = Sitka spruce; DF = Douglas-fir; T = total of all species.

[2]/Plots 2, 6, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 6 was destroyed by the 1962 Columbus Day storm (before remeasurement), plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[3]/Based on plot area of 1 horizontal hectare.

[4]/Quadratic mean diameter.

[5]/Percent of western hemlock in designated plot.

[6]/Based on plots intact in 1968.

Table 17—Number of trees by 2-inch diameter class, year of measurement, and species for trees 1.6+ inches

Year, age (years), and species	Diameter at breast height (inches[1])																								Total[2]
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	
1935 (83):																										
Western hemlock	0	0	0	2	14	23	37	33	25	15	8	4	2	0	0	0	0	0	0	0	0	0	0	0	0	163
Sitka spruce	0	0	0	0	0	1	3	4	5	5	5	5	6	4	4	3	2	1	1	1	0	0	0	0	0	50
Douglas-fir	0	0	0	0	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4
All species[2]	0	0	0	2	15	24	40	37	31	20	14	9	8	5	4	3	2	1	1	1	0	0	0	0	0	217
1940 (89):																										
Western hemlock	0	0	0	1	11	21	31	31	28	16	10	5	3	1	0	0	0	0	0	0	0	0	0	0	0	158
Sitka spruce	0	0	0	0	0	1	3	3	5	4	5	5	5	4	4	3	3	1	1	1	1	0	0	0	0	49
Douglas-fir	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
All species[2]	0	0	0	1	11	22	34	34	33	21	16	10	8	5	4	3	3	1	1	1	1	0	0	0	0	209
1945 (94):																										
Western hemlock	0	0	0	1	9	17	29	29	28	17	13	6	3	2	0	0	0	0	0	0	0	0	0	0	0	154
Sitka spruce	0	0	0	0	0	0	2	3	5	4	4	6	5	5	4	3	3	2	1	1	1	0	0	0	0	49
Douglas-fir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All species[2]	0	0	0	1	9	17	31	32	33	21	17	12	8	7	4	3	3	2	1	1	1	0	0	0	0	203
1955 (104):																										
Western hemlock	0	0	0	0	5	12	21	27	24	20	12	8	5	2	1	0	0	0	0	0	0	0	0	0	0	137
Sitka spruce	0	0	0	0	0	0	1	2	4	3	4	4	5	4	4	3	3	3	1	1	1	1	0	0	0	44
Douglas-fir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All species[2]	0	0	0	0	5	12	22	29	28	23	16	12	10	6	5	3	3	3	1	1	1	1	0	0	0	181
1968 (116):																										
Western hemlock	0	0	0	0	2	7	15	22	20	21	13	10	7	3	1	1	0	0	0	0	0	0	0	0	0	122
Sitka spruce	0	0	0	0	0	0	0	2	3	2	3	4	3	5	3	3	4	2	2	2	1	1	1	0	0	41
Douglas-fir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All species[2]	0	0	0	0	2	7	15	24	23	23	16	14	10	8	4	4	4	2	2	2	1	1	1	0	0	163

[1] To convert inches to centimeters, multiply by 2.54.

[2] Totals in this table are for plots 1, 3, 4, 5, 7, 8, 10, 12, and 13.

Table 18—Volume per acre at age 83 in 1935

Plot[1]	Western hemlock			Sitka spruce			Douglas-fir			All species		
	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]
1	112,449	132,762	20,366	2,821	3,202	490	1,091	1,179	171	116,361	137,143	21,027
3	43,222	50,689	7,706	83,626	91,739	13,399	194	244	41	129,743	142,672	21,146
4	18,289	23,461	3,741	109,526	119,003	17,492	2,570	2,908	433	130,385	145,373	21,666
5	13,983	16,983	2,624	141,343	149,049	21,748	1,371	1,453	210	156,697	167,485	24,582
6	83,343	96,687	14,693	31,026	33,577	4,939	899	1,044	159	115,268	131,308	19,791
7	80,209	95,649	14,782	36,256	39,757	5,865	5,641	6,303	930	122,105	141,710	21,578
8	103,959	132,252	20,994	3,194	3,505	517	399	581	95	107,553	136,338	21,607
9				167,439	179,040	6,228	0	0	0	167,439	179,040	26,228
10	40,997	50,142	7,813	91,467	93,449	13,563	0	0	0	132,469	143,591	21,375
12	74,463	87,685	13,422	29,504	31,891	4,682	0	0	0	103,967	119,576	18,104
13	78,449	94,069	14,554	17,428	18,743	2,751	0	0	0	95,878	112,812	17,305
Mean[5]	62,891	75,966	11,778	57,541	61,149	8,945	1,252	1,408	209	121,684	138,522	20,932

[1] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Scribner rule, trees 11.6+ inches in d.b.h. to a 6-inch top diameter.

[3] International 1/4-inch rule, trees 6.6+ inches in d.b.h. to a 6-inch top diameter.

[4] Trees 5.6+ inches in d.b.h. to a 4-inch top diameter.

[5] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 19—Volume per hectare at age 83 in 1935

Plot[1]	Western hemlock	Sitka spruce	Douglas-fir	Total
		Cubic meters[2]		
1	1425	34	12	1471
3	539	938	3	1480
4	262	1224	30	1516
5	184	1522	15	1720
6	1028	346	11	1385
7	1034	410	65	1510
8	1469	36	7	1512
9	0	436	0	1835
10	547	949	0	1496
12	939	328	0	1267
13	1018	192	0	1211
Mean[3]	824	626	15	1465

[1] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Trees 14+ centimeters in d.b.h. to a 10.2-centimeter top diameter.

[3] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 20—Volume per acre at age 89 in 1940

Plot[1]	Western hemlock			Sitka spruce			Douglas-fir			All species		
	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]
1	121,115	141,924	21,613	2,740	3,075	465	1,186	1,278	185	125,041	146,277	22,263
3	45,712	52,585	7,932	90,267	95,552	13,889	207	260	44	136,187	148,397	21,864
4	20,213	25,470	4,021	118,140	127,803	18,699	2,772	3,128	464	141,126	156,401	23,183
5	15,178	18,190	2,796	149,040	157,039	22,838	1,421	1,508	218	165,639	176,736	25,852
6	90,087	103,406	15,582	33,179	35,585	5,197	967	1,119	170	124,234	140,110	20,950
7	87,117	102,857	15,775	39,217	42,650	6,254	5,872	6,565	968	132,306	152,072	22,998
8	111,343	138,572	21,737	3,485	3,812	560	433	646	105	115,261	143,030	22,402
9	--	--	--	170,941	182,286	26,606	0	0	0	170,941	182,286	26,606
10	41,019	49,260	5,795	99,369	101,446	14,677	0	0	0	140,389	150,707	22,272
12	82,198	95,828	14,555	32,498	34,788	4,079	0	0	0	114,696	130,617	19,634
13	85,677	101,629	15,595	18,971	20,223	2,944	0	0	0	104,648	121,852	18,539
Mean[5]	67,730	80,702	12,402	61,525	65,154	9,489	1,321	1,487	220	130,577	147,343	22,112

[1] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Scribner rule, trees 11.6+ inches in d.b.h. to a 6-inch top diameter.

[3] International 1/4-inch rule, trees 6.6+ inches in d.b.h. to a 6-inch top diameter.

[4] Trees 5.6+ inches in d.b.h. to a 4-inch top diameter.

[5] Based on plots intact in 1968--plots 6 and 9 omitted.

Table 21—Volume per hectare at age 89 in 1940

Plot[1]	Western hemlock	Sitka spruce	Douglas-fir	All species
		Cubic meters[2]		
1	1512	33	13	1558
3	555	972	3	1530
4	281	1308	32	1622
5	196	1598	15	1809
6	1090	364	12	1466
7	1104	438	68	1609
8	1521	39	7	1567
9	0	1862	0	1862
10	405	1027	0	1558
12	1018	285	0	1374
13	1091	206	0	1297
Mean[3]	868	664	15	1547

[1] Plots 2 and 11 are not included; plot 2 was destroyed soon after establishment, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Trees 14+ centimeters in d.b.h. to a 10.2-centimeter top diameter.

[3] Based on plots intact in 1968--plots 6 and 9 omitted.

able 22—Volume per acre at age 94 in 1945

lot[1]	Western hemlock			Sitka spruce			Douglas-fir			All species		
	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]
1	129,200	150,028	22,692	2,663	2,946	440	1,281	1,377	199	133,144	154,351	23,331
3	47,954	54,430	8,157	96,992	102,368	14,836	215	269	45	145,161	157,067	23,037
4	21,838	27,320	4,285	125,746	135,509	19,760	2,876	3,244	480	150,461	166,073	24,526
5	16,204	19,064	2,913	154,961	163,105	23,671	1,478	1,570	226	172,643	183,739	26,810
6	95,054	108,106	16,186	35,751	38,153	5,550	995	1,152	175	131,801	147,412	21,912
7	91,498	107,278	16,363	41,454	44,945	6,568	4,285	4,744	694	137,237	156,968	23,625
8	119,304	146,258	22,746	3,797	4,131	605	0	134	27	123,101	150,523	23,377
10	43,401	51,669	7,933	106,398	108,523	15,672	0	0	0	149,799	160,193	23,605
12	83,920	97,226	14,681	35,093	37,365	5,434	0	0	0	119,012	134,591	20,115
13	90,086	105,976	16,157	21,136	22,403	3,251	0	0	0	111,222	128,380	19,408
lean[5]	71,489	84,361	12,881	65,360	69,033	10,026	1,126	1,260	186	137,976	154,654	23,093

Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by ogging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

Scribner rule, trees 11.6+ inches in d.b.h. to a 6-inch top diameter.

International 1/4-inch rule, trees 6.6+ inches in d.b.h. to a 6-inch top diameter.

Trees 5.6+ inches in d.b.h. to a 4-inch top diameter.

Based on plots intact in 1968--plot 6 omitted.

able 23—Volume per hectare at age 94 in 1945

lot[1]	Western hemlock	Sitka spruce	Douglas-fir	All species
		Cubic meters[2]		
1	1588	31	14	1633
3	571	1038	3	1612
4	300	1383	34	1716
5	204	1656	16	1876
6	1133	388	12	1533
7	1145	460	49	1653
8	1592	42	2	1636
10	555	1097	0	1652
12	1027	380	0	1407
13	1131	227	0	1358
ean[3]	901	702	13	1616

Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after stablishment, plot 9 was accidentally destroyed by logging, and plot 11 ontained substantial amounts of young Douglas-fir and red alder.

Trees 14+ centimeters in d.b.h. to a 10.2-centimeter top diameter.

Based on plots intact in 1968--plot 6 omitted.

Table 24—Volume per acre at age 104 in 1955

Plot[1]	Western hemlock			Sitka spruce			Douglas-fir			All species		
	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]
1	134,600	154,344	23,137	2,791	3,050	488	1,448	1,553	223	138,840	158,946	23,808
3	49,164	55,292	8,220	108,490	114,143	16,462	0	0	0	157,654	169,435	24,682
4	24,862	30,721	4,767	139,623	149,725	21,708	3,117	3,513	518	167,602	183,960	26,993
5	17,718	20,521	3,108	160,835	168,612	24,359	1,584	1,686	242	180,137	190,819	27,709
6	104,444	118,091	17,561	40,354	42,865	6,204	714	812	120	145,512	161,768	23,886
7	101,226	117,345	17,750	48,001	51,784	7,526	3,511	3,906	571	152,739	173,045	25,848
8	128,022	153,854	23,618	3,730	4,018	582	0	0	0	131,752	157,873	24,200
10	41,451	48,810	7,431	120,420	122,760	17,666	0	0	0	161,870	171,570	25,097
12	94,276	107,856	16,134	40,658	42,920	6,201	0	0	0	134,934	150,777	22,335
13	96,403	111,550	16,806	23,766	24,831	3,575	0	0	0	120,168	136,381	20,381
Mean[5]	76,414	88,922	13,441	72,035	75,760	10,947	1,073	1,184	173	149,522	165,867	24,561

[1] Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Scribner rule, trees 11.6+ inches in d.b.h. to a 6-inch top diameter.

[3] International 1/4-inch rule, trees 6.6+ inches in d.b.h. to a 6-inch top diameter.

[4] Trees 5.6+ inches in d.b.h. to a 4-inch top diameter.

[5] Based on plots intact in 1968--plot 6 omitted.

Table 25—Volume per hectare at age 104 in 1955

Plot[1]	Western hemlock	Sitka spruce	Douglas-fir	All species
		Cubic meters[2]		
1	1619	34	16	1666
3	575	1152	0	1727
4	334	1519	36	1889
5	217	1704	17	1939
6	1229	434	8	1671
7	1242	527	40	1809
8	1653	41	0	1693
10	520	1236	0	1756
12	1129	434	0	1563
13	1176	250	0	1426
Mean[3]	940	766	12	1719

[1] Plots 2, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Trees 14+ centimeters in d.b.h. to a 10.2-centimeter top diameter.

[3] Based on plots intact in 1968--plot 6 omitted.

Table 26—Volume per acre at age 116 in 1968

Plot[1]	Western hemlock			Sitka spruce			Douglas-fir			All species		
	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]	Board feet[2]	Board feet[3]	Cubic feet[4]
1	139,931	159,046	23,628	3,097	3,393	496	1,620	1,739	249	114,649	164,178	24,373
3	51,892	57,991	8,558	120,476	126,421	18,161	0	0	0	172,368	184,412	26,719
4	28,369	33,550	5,113	157,972	168,656	24,313	2,800	3,136	459	189,141	205,342	29,885
5	19,484	22,360	3,349	170,615	178,909	25,740	1,766	1,883	269	191,865	203,151	29,359
7	105,459	120,793	18,091	54,556	58,280	8,418	4,042	4,538	670	164,057	183,611	27,179
8	141,699	166,575	25,261	4,260	4,585	661	0	0	0	145,959	171,161	25,922
10	40,473	46,461	6,965	135,537	138,464	19,884	0	0	0	176,010	184,924	26,849
12	105,251	119,287	17,676	45,579	47,679	6,838	0	0	0	150,829	166,966	24,514
13	102,842	117,008	17,436	28,673	29,857	4,285	0	0	0	131,515	146,864	21,721
Mean[5]	81,711	93,675	14,009	80,085	84,027	12,088	1,136	1,255	183	162,933	178,957	26,280

[1] Plots 2, 6, 9, and 11 are not included.

[2] Scribner rule, trees 11.6+ inches in d.b.h. to a 6-inch top diameter.

[3] International 1/4-inch rule, trees 6.6+ inches in d.b.h. to a 6-inch top diameter.

[4] Trees 5.6+ inches in d.b.h. to a 4-inch top diameter.

[5] Based on plots intact in 1968.

Table 27—Volume per hectare at age 116 in 1968

Plot[1]	Western hemlock	Sitka spruce	Douglas-fir	All species
		Cubic meters[2]		
1	1653	35	17	1705
3	599	1271	0	1870
4	358	1701	32	2091
5	234	1801	19	2054
7	1266	589	47	1902
8	1768	46	0	1814
10	487	1391	0	1879
12	1237	478	0	1715
13	1220	300	0	1520
Mean[3]	980	846	13	1839

[1] Plots 2, 6, 9, and 11 are not included; plot 2 was destroyed soon after establishment, plot 6 was destroyed by the 1962 Columbus Day storm (before remeasurement), plot 9 was accidentally destroyed by logging, and plot 11 contained substantial amounts of young Douglas-fir and red alder.

[2] Trees 14+ centimeters in d.b.h. to a 10.2-centimeter top diameter.

[3] Based on plots intact in 1968.

Table 28—Summary of stand characteristics of all plots, per acre basis, 1935-68

Species	Year	Age	Basal area	Average d.b.h. 1/	Number of trees	Volume		
		Years	Square feet	Inches		Board feet 2/	Board feet 3/	Cubic feet 4/
All species	1935	83	417	18.7	218	121,684	138,522	20,932
	1940	89	431	19.4	211	130,577	147,343	22,112
	1945	94	442	20.0	203	137,976	154,654	23,093
	1955	104	455	21.2	185	149,522	165,867	24,561
	1968	116	468	22.8	166	162,933	178,957	26,280
Western hemlock	1935	83	237	16.2	165	62,891	75,966	11,778
	1940	89	244	16.8	159	67,730	80,702	12,402
	1945	94	249	17.3	153	71,489	84,361	12,881
	1955	104	251	18.2	139	76,414	88,922	13,441
	1968	116	252	19.4	123	81,711	93,675	14,009
Sitka spruce	1935	83	176	25.1	51	57,541	61,149	8,945
	1940	89	183	26.0	50	61,525	65,154	9,489
	1945	94	190	26.7	49	65,360	69,033	10,026
	1955	104	200	28.4	45	72,035	75,760	10,947
	1968	116	212	30.6	42	80,085	84,027	12,088
Douglas-fir	1935	83	4	20.3	2	1,252	1,408	209
	1940	89	4	20.5	2	1,321	1,487	220
	1945	94	4	21.1	1	1,126	1,260	186
	1955	104	3	21.9	1	1,073	1,184	173
	1968	116	3	23.2	1	1,136	1,255	183

1/Quadratic mean diameter.

2/Scribner rule, trees 11.6+ inches d.b.h. to a 6-inch top diameter.

3/International 1/4-inch rule, trees 6.6+ inches in d.b.h. to a 6-inch top diameter.

4/Trees 5.6+ inches in d.b.h. to a 4-inch top diameter.

Table 29—Summary of stand characteristics of all plots, per hectare basis, 1935-68

Species	Year	Age	Basal area	Average d.b.h. [1]	Number of trees	Volume [2]
		Years	Square meters	Centimeters		Cubic meters
All species	1935	83	38.7	47.5	539	1465
	1940	89	40.0	49.3	521	1548
	1945	94	41.1	50.8	502	1616
	1955	104	42.3	53.8	457	1719
	1968	116	43.5	57.9	410	1839
Western hemlock	1935	83	22.0	41.1	408	824
	1940	89	22.7	42.7	393	868
	1945	94	23.1	43.9	378	902
	1955	104	23.3	46.2	343	941
	1968	116	23.4	49.3	304	980
Sitka spruce	1935	83	16.4	63.8	126	626
	1940	89	17.0	66.0	124	664
	1945	94	17.7	67.8	121	702
	1955	104	18.6	72.1	111	766
	1968	116	19.7	77.7	104	846
Douglas-fir	1935	83	.37	51.6	5	15
	1940	89	.37	52.6	5	15
	1945	94	.37	53.6	2	13
	1955	104	.28	55.6	2	12
	1968	116	.28	58.9	2	13

[1] Quadratic mean diameter.

[2] Trees 14+ centimeters in d.b.h. to a 10-centimeter top diameter.

Table 30—Summary of gross rate of growth per acre, 1935-68

Volume by species	Age (years)					Period			
	83	89	94	104	116	1935-40	1941-45	1946-55	1956-68
	MEAN ANNUAL INCREMENT[1/]					PERIODIC ANNUAL INCREMENT[2/]			
Western hemlock:									
Board feet (Scribner rule) to a 6-inch top	758	761	761	735	704	807	752	493	441
Board feet (International 1/4-inch rule) to a 6-inch top	915	907	897	855	808	789	732	456	396
Cubic feet to a 4-inch top	142	139	137	129	121	104	96	56	47
Sitka spruce:									
Board feet (Scribner rule) to a 6-inch top	693	691	695	693	690	664	767	668	671
Board feet (International 1/4-inch rule) to a 6-inch top	737	732	734	728	724	668	776	673	689
Cubic feet to a 4-inch top	108	107	107	105	104	91	107	92	95
Douglas-fir:									
Board feet (Scribner rule) to a 6-inch top	15	15	12	10	10	12	-39	- 5	5
Board feet (International 1/4-inch rule) to a 6-inch top	17	17	13	11	11	13	-45	- 8	6
Cubic feet to a 4-inch top	3	2	2	2	2	2	- 7	1	1
All species:									
Board feet (Scribner rule) to a 6-inch top	1,466	1,467	1,468	1,438	1,405	1,482	1,480	1,155	1,118
Board feet (International 1/4-inch rule) to a 6-inch top	1,669	1,656	1,645	1,595	1,543	1,470	1,462	1,121	1,091
Cubic feet to a 4-inch top	252	248	246	236	227	197	196	147	143

[1/] (Total volume/acre at age_i)/age_i.

[2/] (Total volume at age_{i+1} - total volume age_i)/(age_{i+1}-age_i).

Table 31—Summary of gross rate of growth per hectare, 1935-68

Volume by species	Age (years)					Period			
	83	89	94	104	116	1935-40	1941-45	1946-55	1956-68
	MEAN ANNUAL INCREMENT[1/]					PERIODIC ANNUAL INCREMENT[2/]			
Western hemlock:									
CV10.2[3/]	9.9	9.7	9.6	9.0	8.4	7.3	6.7	3.9	3.3
Sitka spruce:									
CV10.2[3/]	7.5	7.5	7.5	7.4	7.3	6.3	7.5	6.4	6.6
Douglas-fir:									
CV10.2[3/]	.2	.2	.1	.1	.1	.1	-.5	-.1	.1
All species:									
CV10.2[3/]	17.6	17.4	17.2	16.5	15.8	13.8	13.7	10.3	10.0

[1/] (Totalvolume/hectare at age_i)/age_i.

[2/] (Total volume at age_{i+1} - total volume age_i)/(age_{i+1}-age_i).

[3/] Cubic meters to a 10.2-centimeter top.

Smith, Stephen H.; Bell, John F.; Herman, Francis R.; See, Thomas. Growth and yield of Sitka spruce and western hemlock at Cascade Head Experimental Forest, Oregon. Res. Pap. PNW-325. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 30 p.

A study established in 83-year-old, even-aged stands of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) at Cascade Head Experimental Forest in the Siuslaw National Forest on the Oregon coast traces their development for 33 years. Statistical data collected from 12 permanent sample plots during four periods of growth illustrate the tremendous productive capacity of the Sitka spruce–western hemlock type.

Keywords: Increment (volume), stand volume, increment (basal area), increment (height), even-aged stands, Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*.

1 2

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